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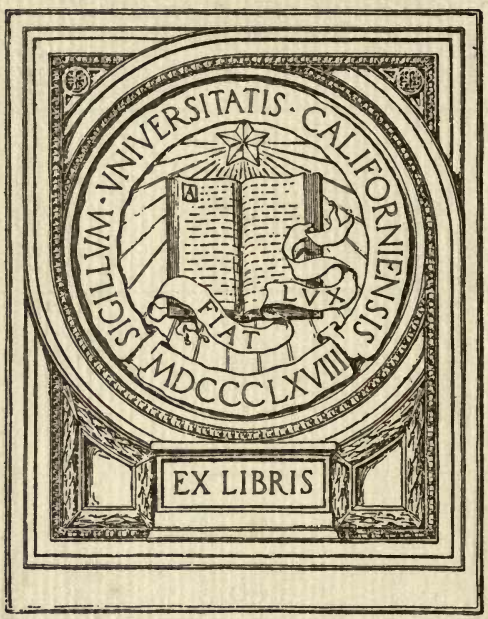

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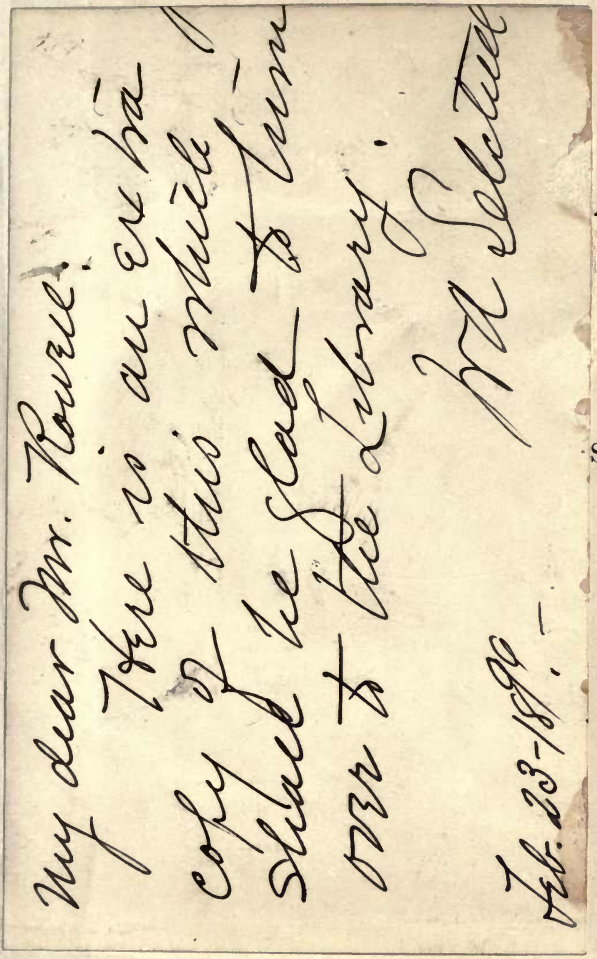
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A LABORATORY MANUAL

IN

PRACTICAL BOTANY

BY

CHARLES H. CLARK, A.M., D.Sc.
PRINCIPAL OF WINDSOR HALL SCHOOL

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CONTENTS.

PAGE

INTRODUCTION 7

PRELIMINARY STUDIES 14

I. THE SLIME FUNGI (*Myxomycetes*) 50

II. THE DIATOMS (*Diatomaceæ*) 54

III. THE FISSION PLANTS (*Schizophytes*) 59
Class I. The Blue-Green Slimes (*Cyanophyceæ*) . 59
Class II. The Bacteria (*Schizomycetes*) . . . 63

IV. THE ALGÆ 70
Class I. The Green Algæ (*Chlorophyceæ*) . . 71
Class II. The Brown Algæ (*Phæophyceæ*) . . 110
Class III. The Red Algæ (*Rhodophyceæ* or *Florideæ*) 118

V. THE FUNGI 120
Class I. The *Chytridieæ* 121
Class II. The Smut Fungi (*Ustilagineæ*) . . . 122
Class III. The Molds and Mildews (*Phycomycetes*) . 125
Class IV. The Sac Fungi (*Ascomycetes*) . . . 136
Class V. The Rusts (*Æcidiomycetes*) . . . 157
Class VI. The Toadstools and their Allies (*Basidiomycetes*) 160

VI. THE BRYOPHYTES 167
Class I. The Liverworts (*Hepaticæ*) . . . 167
Class II. The Mosses (*Musci*) 176

PAGE

VII. The Pteridophytes 183
Class I. The True Ferns (*Filicinæ*) . . . 186
Class II. The Horsetails (*Equisetinæ*) . . . 200
Class III. The Club Mosses (*Lycopodinæ*) . . . 202

VIII. The Spermaphytes 205
Class I. The Gymnosperms 206
Subclass I. The Cycads . . . . .
Subclass II. The Conifers . . . . .
Subclass III. The Joint Firs . . . . .
Class II. The Angiosperms 218
Subclass I. The Monocotyledons . . . 220
Subclass II. The Dicotyledons 225

APPENDIX

The Cultivation of the Lower Plants for Laboratory Use 257

Reagents, Culture Media, and Staining Fluids . . 264

General Index 267

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A LABORATORY MANUAL IN PRACTICAL BOTANY.

INTRODUCTION.

Good authorities estimate that there are more than one hundred and fifty thousand species of plants. In the study of this vast number of different forms we need a framework to build on that will give form and substance to our ideas, placing the facts acquired in positions where we shall be able to find and use them. In the following pages the practical studies have been made to take their appropriate places in a brief outline of classification, to the end that the student's knowledge may assume definiteness of form.

Many and various schemes of classification have been employed, which differ more or less in accordance with the varying ideas of different investigators, and because of the impossibility of agreement as to the position of certain forms. In the case of the Flowerless Plants, the difficulties of classification are especially great. New plants are frequently discovered. New facts come to light about known organisms which sometimes show that forms which have been considered as separate plants are really only different stages in the development of a single plant; and points that have been considered as fixed in the classification become unsettled. Any classification, especially in the case of the lower groups, must, therefore, be looked upon as merely provisional, and subject to

change as investigations bring to light new knowledge. The development of plant life has not been direct from the simple one-celled plants up to the complicated structures of the highest types, but different lines of development have been followed, producing puzzling complications when an attempt is made to locate the forms in a classification.

To gain a clear and consistent conception of plant life, the logical order of study is from the lowest to the highest forms. Some teachers of undoubted authority do not, however, consider this to be the best order for beginners to meet the subject. The course of which the present exercises form a part contemplates a considerable amount of previous study of the gross morphology of seeds, roots, stems, leaves, flowers, and fruits of the Flowering Plants, with considerable attention to the divisions into groups and classes, and with sufficient attention to analysis to enable the student to find the names of plants. With this preparation it seems to the writer that the student can enter with profit upon a course which will give him a general view of the whole plant world, beginning with plants of the simplest organization. In the lowest forms we come closest to the processes of nature, and, as we advance in the study of the higher orders, our development in knowledge follows nature in her development of processes. In the lowest forms we study simple masses of protoplasm; as we go on from one simple plant to another of somewhat higher type, we learn how, under the mysterious laws of nature, the same elementary substances are combined to produce the myriads of different forms of plant structure. Botany becomes to us something very different from the assorting of various forms and memorizing barbarous Latin and Greek names. The value of the knowledge how to determine the name of a plant by means of a key to the classification should not

be underrated; but too much cannot be said against that view of the science which still prevails in many schools, that the sole purpose of the study of botany is to learn the names of plants.

A point of quite general agreement in the classification of plants, and one that is sufficient for the beginner, is a division into the four groups of *Thallophytes*, or plants which have no true roots, stems, or leaves; *Bryophytes*, or Moss plants; *Pteridophytes*, or Fern plants; and *Spermaphytes*, or Seed plants.

The Thallophytes. — These plants include a very large number of lowly organized forms. They are distinguished from all the plants above them by the fact that they are either unbranched, or are divided into branches which are just alike in structure; in other words, they show no differentiation into stem, root, and leaf, though in some plants there is a foreshadowing of such differentiation. The plant body is called a *thallus*. There is a more or less regular alternation of generations between forms which produce simple *spores* and forms that produce cells which unite sexually and give rise to a *zygospore*, or *oöspore*, from which a new plant develops, though in many of the Thallophytes this alternation of generations is unknown, or is wanting. The sexual cells are known as *gametes;* the form of the plant which bears them is the *gametophyte*. The form of the plant which bears simple spores is known as the *sporophyte*. This alternation of generations between gametophyte and sporophyte is by no means confined to the Thallophytes. It extends in general throughout the whole vegetable kingdom, and is more highly marked in other groups than it is in the Thallophytes. In the case of the Thallophytes, the form which bears the name is usually the gametophyte, as this is the most highly developed form of the plant. Another fact which distinguishes the Thallophytes is that the female gamete is never an

archegonium, while in all the other groups it is essentially an archegonium. The three higher groups are, therefore, sometimes grouped together as *archegoniates*. The Thallophytes, also, in many cases reproduce themselves asexually by cell division, and by the formation of sporelike cells called *gonidia*, which are distinguished from ordinary spores by the fact that they do not enter into the alternation of generations. Ordinary spores are borne by sporophytes, and develop into gametophytes. Gonidia are borne by gametophytes, and develop into gametophytes.

The Bryophytes. — Here also the ordinary form of the plant is the gametophyte. The alternation of generations is well marked. The ordinary Moss plants produce male gametes, *antherozoids* or *spermatozoids*, and female gametes, *oöspheres*. These unite and produce *oöspores*, which develop in the archegonium into sporophytes. The sporophyte produces spores, which grow first into small, flat cell aggregates known as *protonemæ*. The protonema throws out lateral, or in some cases terminal, buds, which develop into gametophytes or ordinary Moss plants. There is no reproduction by the formation of gonidia, as in the Thallophytes, but there is a vegetative reproduction by *gemmæ*, which form on various parts of the gametophyte. A differentiation into root, stem, and leaf appears in a rudimentary form. There are no true roots, but unicellular or multicellular filaments known as *rhizoids* perform the functions of roots. Rudimentary fibrovascular bundles also make their appearance.

The Pteridophytes. — Here, in contrast with the Thallophytes and Bryophytes, the ordinary form of the plant is the sporophyte. The alternation of generations is sharp. The spore develops into a flat aggregate of cells called the *prothallium*, which resembles in function the protonema of the Bryophytes. The prothallium is the gametophyte. It bears in specially differentiated cells *antherozoids* or

spermatozoids, the *male gametes*, which fertilize other specially differentiated cells, the *oöspheres* or *female gametes*. The *oöspore*, which results from this fertilization, develops into the sporophyte or ordinary Fern plant. The differentiation into root, stem, and leaf is well marked, as is also the development of fibrovascular bundles.

The Spermaphytes. — Here also the ordinary form of the plant is the sporophyte. Two kinds of spores are borne, — *microspores* or *pollen grains*, and *macrospores* or *embryo sacs*. Each kind of spore develops into a minute prothallium, and these prothallia represent the gametophyte. The male gamete is either the original nucleated protoplasm of the pollen grain, or is one of the nucleated cells formed by the division of that protoplasm in the formation of the male prothallium in a tube which grows out of the pollen grain. The female gamete is a nucleated cell situated near one end of the female prothallium, which is formed in the embryo sac in the ovary of the pistillate flower. From the fertilization of the female gamete by the male gamete there results a seed which distinguishes this group from the three lower groups. The differentiation into root, stem, and leaf, and the development of the fibrovascular bundles reach their perfection in the Spermaphytes.[1]

Beyond this grouping of all plants into Thallophytes,

[1] It is not expected that the beginner will gain very definite ideas of the facts which have determined these four great groups from reading the preceding paragraphs. A clear conception of these facts will come only after the actual observation and study of plants which show these distinguishing characteristics. Attention will frequently be called to these points in connection with the practical studies of plants in the following pages. Whenever attention is thus directed to the principles which have led to the separation of all plants into these four groups, the pupil should read and reread these paragraphs until he gains a clear conception of the principles.

Bryophytes, Pteridophytes, and Spermaphytes, there is less agreement among the authorities. Different principles have governed the separation into subdivisions. The terms *group*, *branch*, *class*, *order*, and *family* are variously and arbitrarily used by writers, and a comparison of the schemes of classification of different authorities usually leads to confusion of ideas. In the writer's judgment too much stress should not be laid on classification in the case of the beginner, and the minutiæ of classification should be wholly omitted. At the same time some outline of classification seems an absolute necessity to aid the student in arranging the facts he acquires.

The scheme of classification which forms the framework for the following pages is, with some slight modifications, that given by Goebel in his "Outlines of Classification and Special Morphology of Plants." Its main features are presented in the tabular view.

THE FLOWERING PLANTS.

The Dicotyledonous Angiosperms.

1. Soak seeds of the Bean, Pea, Squash, Mustard, Buckwheat, and Flax in water over night. Then cover them half an inch deep in sawdust kept moist, — not drenching wet, — and in a warm, light place, until they germinate and grow into little plants from one to three or four inches high. Other seedlings of these plants may be grown in moist earth. If the earth has been previously baked, growths of weeds will give less trouble. It is a good plan to make several plantings, at intervals of a few days, to secure plants at various stages of development.

2. Make examinations of the little plants from the time the *seed coats*, or outer coverings of the seeds, begin to split open until the plants have attained considerable size. Represent them by outline drawings in the different stages of development. Do the seed coats all split open in the same way? What becomes of the seed coat? Of how many parts does the portion within the seed coat consist? Do these parts — the *cotyledons* — remain underground, or are they raised above its surface? Do you find any evidence that a plant does work? Are the cotyledons of seeds generally raised above ground? How many instances do you know of in which they are not? The portion of the stem that holds the cotyledons above ground is the *hypocotyl*. The cotyledons are modified leaves; they are storehouses of nourishment for the first growth of the plant. Does the rapidity of the first growth appear to depend upon the amount of nourishment stored up in the cotyledons? Watch the cotyledons as the plants become older; do they develop? If not, what does become of them? Plants in which the cotyledons expand equally in the first growth are called *Dicotyledons*.

3. Examine large Beans and Peas, some dry and some that have been soaked over night. On the outside of the *testa*, or *seed coat*, notice the scar — *hilum* — where the seed was attached, and near it a small opening, — the *micropyle*. Use a magnifying glass to see the micropyle. Split the seeds. Near the hilum, and lying between the two cotyledons, find a miniature plant. At one end of this is the *radicle*, — a small pointed organ. Connected with the radicle is a delicate structure which a good magnifying glass will show to be composed of minute beginnings of leaves, — the *plumule*. Examine also for these structures Peas and Beans that have been germinating from one to five days. How are the radicle and plumule located in the seeds with reference to the hilum and micropyle? The use of the micropyle will be considered later.

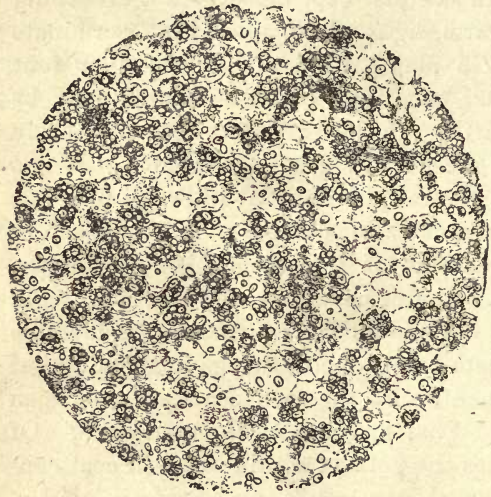

FIG. 1. — Section through a cotyledon of a Bean, showing starch and aleurone granules in the cells. Starch and aleurone are the nutrient materials stored up for the future growth of the plant. When the seed germinates, these substances are converted into *sugar*, which is the form in which the food passes from one part of the plant to another. (× 35.)

4. The cotyledons and the plumule and radicle with the minute hypocotyl constitute the *embryo*. In the Bean and the Pea, the stores of food that are to serve the plant in the beginning of its growth, are in the cotyledons.

This is not always the case; a considerable variety of arrangements occur. Using seeds of common plants, soaking them over night, cut through so as to show the location of the embryo, which will sometimes be found imbedded in the stored-up food, and sometimes situated so as to inclose it. When the stored-up food is not in the cotyledons, it is known as *albumen* or *endosperm*. Seeds containing it are *albuminous;* those not containing it are *exalbuminous*. Draw all the different types found. Dissect out some of the embryos whole. Seeds of Four-o'clock, Poppy, Barberry, Asparagus, Locust, Spring Beauty, and numerous other plants will serve for these observations.

5. Trace the development of the radicle in seedlings of different ages. What is the direction of its growth? Place on their sides seedlings that have well-developed radicles, covered in moist sawdust, so that their radicles and plumules point horizontally. In twenty-four hours examine. The radicles have obeyed an influence which has turned them towards the center of the earth. This influence is believed to be the attraction of gravitation; its manifestation is called *geotropism*, and the movement is a *geotropic* movement.

6. As the radicles grow, do they branch? If so, is there any uniformity in the mode of branching? Do any of the radicles develop into a *taproot*, *i.e.*, a root that grows straight towards the center of the earth? If there is a taproot, where do the *secondary roots*, *i.e.*, those that form after the *primary root* has become well started, have their origin?

7. Near the tip ends of the youngest roots find with a magnifying glass minute hairs. Do they cover the tip of the root? If not, about how far from the tip do you find them? As the roots increase in age, the hairs die away, and new ones are formed on the newer portions of the root.

These hairs are of the utmost importance in the economy of the plant. They are the principal organs of absorption for the nutrient fluids of the plant. The fluids enter them from the soil by the physical process of *osmosis*. These fluids contain the dissolved mineral and organic matters which furnish food for the plant. They pass from cell to cell up to the very tops of the loftiest trees. It is known that osmotic action has much to do with this passage of the fluid, but it is still an unsolved problem why the osmosis should be so much stronger from without inward than it is from within the plant outward. Because it is stronger from without, there results a pressure, known as *root pressure*, which carries the fluids up into the plant and keeps up a supply of food.

8. Trace the development of the plumule. When the seedling was placed in the horizontal position in Number 5, the plumule soon turned upward from the earth. The movement is called an *apogeotropic* movement.

9. Place a well-developed seedling in a position where it will receive the light on only one side. Notice that after some time it turns its leaves towards the light, or exhibits *heliotropism*.

10. Observe the arrangement of the leaves on the young stems. Is the arrangement the same in all of these plants? Describe the leaf arrangements you find, whether the leaves are *opposite* one another, or are arranged *alternately*. If opposite, consider the positions of successive pairs. If alternate, count the number of leaves in one complete revolution about the stem.

Are the leaves first produced by the seedlings of the same shape as those formed after the plants have attained considerable size? If not, describe the differences for each plant and illustrate by outline drawings. Are the lower leaves in all cases as well developed as those formed later? As we shall consider more fully later, a large part

of the food of the plant enters through the leaves. If you find that some of the lower leaves are not so well developed as the later ones, consider the cotyledons and see if you can give any reason for the difference.

11. Draw one of the latest formed leaves of each seedling, showing the *venation*, or arrangement of the *veins*, in each. Are the leaves *netted-veined*, *i.e.*, do the veins form interlacing network, or are they *parallel-veined*, *i.e.*, do the veins run parallel, or nearly parallel, to one another? Netted-veined leaves are characteristic of the Dicotyledons. Parallel-veined leaves are, in general, characteristic of the Monocotyledons.

12. Consider the shapes of the different leaves. Find, by consulting the figures and descriptions in Gray's "Manual of Botany," what names are applied to the different shapes. Also consider the edges of the leaves and find what names are used to designate them.

13. Examine the venation, shape, and edges of the leaves of a number of common plants, *e.g.*, House Geranium (*Pelargonium*), Wild Geranium, India Rubber Plant, Willow, Maple, Horse-chestnut, Birch, Apple, Beech, Elder, Oak, Cherry, Lilac, Currant, Loosestrife, Begonia, etc. Find names to describe the shapes and edges of each. Twigs of many of the common trees will put forth their leaves even in midwinter, if they are placed with their cut ends in water in warm places.

14. Examine the *vernation* of the leaves of the plants mentioned in Number 13 and of other similar plants. Vernation is the name applied to the arrangement of the undeveloped leaf in the bud. Dissect some of the buds, cut some transversely, some longitudinally, examine with a magnifying glass, and consult Gray's "Manual of Botany" for the names given to the different shapes found. This study should be made on buds just ready to open in the spring or on those forced to open.

15. Examine the arrangement of the leaves on the plants mentioned in Number 13. The points on the stem where the leaves originate are called *nodes;* the spaces between the nodes are *internodes.* On these or on other plants find cases where the arrangement is *opposite*, *i.e.*, two at each node, one opposite the other; cases where the arrangement is *alternate*, *i.e.*, only one at each node; other cases where the leaves are in whorls, *i.e.*, several at each node, arranged around the stem. Examine as many common house and outdoor plants as possible. The position of the leaves of the previous summer may be seen on the winter stem by the *leaf scars*, one at the base of each bud that has formed for the following season. What arrangement do you find to be the most common?

16. Select twigs on which the leaves are arranged alternately. Starting with any leaf, wind a string around the twig so as to pass by the base of each leaf. Determine whether the number of leaves passed in each revolution about the stem is constant. Do you find the arrangement the same in all the plants examined? State what number of leaves you find in one revolution about the stem in each different case. Select a straight stem, and with a knife cut a line vertically down from the base of each leaf found in one revolution about the stem. What portion of the circumference of the stem lies between each two consecutive leaves? Is this fraction the same in all cases examined? The arrangement of the leaves on the stem is called *phyllotaxy.*

17. Consider the parts of a typical leaf, as of the Strawberry, Wild Geranium, House Geranium, Rose, Red Clover, Apple, etc. The broad, expanded portion is the *blade* or *lamina;* the stem supporting the blade is the *petiole* or *leaf stalk;* at the base of the petiole are the *stipules.* Find leaves that have no petioles; such leaves are said to be *sessile.* Find leaves that have no stipules. Find cases

in which the stipules have developed into *spines*. Find cases in which the stipules are united and perhaps encase the petiole to some extent.

18. Tear off small bits of the epidermis from the upper and under sides of a leaf, the Lilac leaf, for instance. Place it on a microscope slide in a drop of water, outside surface uppermost, and place a cover glass over it. Examine with the low power of the compound microscope for *stomata*, or minute openings into the interior of the leaf. Each stoma is inclosed by special cells, the *guard cells*. The stomata are very important organs. The little cells between which the openings pass open and close under the changes of moisture contained in the plant and under the influence of light. They control the *transpiration* of the water from the plants. Transpiration is the name given to the passing of the water out of the plant into the air; it is more than simple evaporation, for its amount depends upon the pressure of the fluids within. Root pressure and the control of the transpiration by the stomata regulate the supply of food materials brought up from the soil by the sap, according to the necessities of the plant.

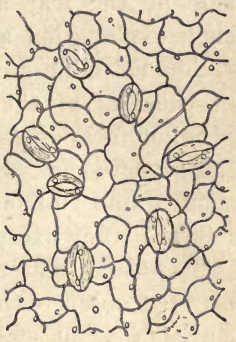

FIG. 2.—Stomata of Lilac leaf.

On which side of the leaf do you find stomata more abundant? Make similar studies of the stomata of other leaves. Draw portions of several specimens, showing the stomata and the superficial cells of the epidermis. Are the stomata invariably more abundant on either the upper or under side of the leaf? If so, on which side?

Examine some of the stomata under high power. Draw, showing stomata and epidermal cells.

Through the epidermis of the leaf, mainly that on the

upper side, there is an exchange of gases by osmosis. Oxygen, which is given off by the plants as a waste product, passes out; carbon dioxide from the air, which is a food for the plant, passes in. More than one half of the solid matter of plants is carbon derived from this source.

19. Tear off bits of the epidermis from the upper and under surfaces of the leaf of the White Water Lily (*Nymphæa odorata*) and the Yellow Water Lily (*Nuphar advena*) and examine for stomata. Draw. On which side of the leaf are they the more abundant? Make such explanation as you can of what you find.

20. Examine stomata obtained from around the edges of the leaf of the Nasturtium (*Tropæolum majus*). A peculiar form of stoma is illustrated by this observation, the *water stoma*. Such stomata occur in a comparatively small number of plants. They take their name from the fact that they excrete water in drops.

21. Using material similar to that mentioned in Number 13, observe the buds growing in the *axils* of the leaves, *i.e.*, just above the point of attachment of the petiole with the stem. Some of these buds will develop into leafy branches, some simply into leaves, some into flowers, and many will not develop at all.

Sometimes several buds grow in the axil of the same leaf. These are called *accessory* or *supernumerary buds*. Examine branches of Red Maple or Walnut for such buds.

Adventitious buds are those that form at other places than at the ends of branches or in the axils of leaves. The Willow is perhaps the best plant on which to study them. Twigs from Willow hedges or trees that have been kept cut back are sure to show them.

Terminal buds are those that form at the ends of branches.

22. Consider the structure of flowers. The Star Flower (*Trientalis Americana*), May Apple (*Podophyllum*

peltatum), Spring Beauty (*Claytonia Virginica*), Wood Sorrel (*Oxalis acetosella*), St. John's Wort (*Hypericum perforatum*), Wild Geranium (*Geranium maculatum*), some varieties of the House Geranium (*Pelargonium*), or any other wild or cultivated flower, selected by the teacher, may be used in this study. Consult Gray's "School and Field Botany," pp. 79–104, for the plan of a typical flower and the names of the various parts.

Find in the flower studied and represent by outline drawings a *sepal*, *petal*, *stamen*, *pistil*, *torus*. The sepals constitute the *calyx;* the petals, the *corolla*. On the drawing of the stamen, letter to show the *filament*, *anther*, and the *dehiscence* of the anther, *i.e.*, the manner in which it splits open to discharge the *pollen*. Examine under the high power of the compound microscope as many different kinds of pollen as you find. See Gray's "School and Field Botany," Figs. 309–318. On the drawing of the pistil, letter to show the *ovary*, *style*, and *stigma*. Cut open the ovaries of several different flowers, both transversely and longitudinally. Study them under a magnifying glass and represent both sections in drawings, making the ovules as distinct as possible. Also draw an entire flower, showing all the parts as distinctly as possible, labeling each.

A flower that has both stamens and pistils is a *perfect* or *hermaphrodite* flower; one that has all the parts is a *complete* flower. Many flowers are incomplete. Some lack either sepals or petals; others lack both, and are said to be naked. Flowers that have stamens, but no pistils, are *staminate*; those having pistils, are *pistillate*. When both staminate and pistillate flowers are borne on the same plant, it is *monœcious;* when the staminate flowers are borne on one plant and the pistillate on another, the plants are *diœcious*. Other plants are polygamous, *i.e.*, some of the flowers are perfect, some pistillate, some staminate.

In a typical complete flower each of the parts is separate, all being inserted on the torus. The greatest variety of variations from this type occur. The pistils are frequently united through the whole or a part of their length; so also the stamens. If the petals are separate, the flower is *polypetalous;* if united, as in the Mayflower, Blueberry, and Rhodora, the flower is *gamopetalous.* If the sepals are separate, the flower is *polysepalous;* if united, as in Ground Ivy, Locust, Carnation, Bouncing Bet, Toad Flax, the flower is *gamosepalous.* Some flowers are both gamopetalous and gamosepalous, as the Bluet, Partridge Vine, Harebell, Twin Flower, and Fringed Gentian.

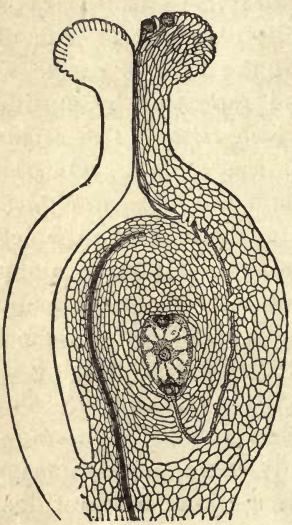

FIG. 3. — Diagram of a longitudinal section of an ovary having only one ovule with basal placentation, designed to exhibit the course of the pollen tube from the stigma to the summit of the embryonal sac above the oösphere. The ovule is anatropous, and is inserted, as is usually the case in Compositæ. (Luerssen.)

23. *The fertilization of the flower.* — Before the flower can perform the function for which it was designed, namely, produce seed, it must be fertilized. Pollen grains from the same or different flowers are brought in contact with the stigma. Here they begin to grow and send down long tubes through the style to the ovaries. The contents of the pollen grains pass down through these tubes and enter certain cells in the ovaries. These cells, the *ovules*, then develop into seeds. The micropyle, already observed on the Bean and Pea, marks the place where the pollen tube entered the ovule.

Even when flowers have both stamens and pistils, *self*

fertilization, *i.e.*, fertilization of the ovary by pollen produced in an anther on the same flower, is the exception. *Cross fertilization*, or fertilization by pollen borne on some other plant of the same or a closely related species, is the rule. Self fertilization tends to deterioration; cross fertilization tends to produce stronger and healthier plants.

To effect cross fertilization the pollen is carried by the wind, by insects, and in some cases by birds. As a rule plants that do not bear colored flowers are fertilized by the wind, or are *anemophilous;* those that bear colored or conspicuous flowers are *entomophilous*, *i.e.*, are fertilized by insects or birds. The colors, fragrance, and honey in flowers are contrivances of nature to attract insects, which carry the pollen from one flower to another as they search for their food. Not only do we owe the beautiful colors and sweet odors of flowers to this necessity of receiving pollen from other plants, but nature has caused the parts of flowers to assume a great variety of curious and interesting shapes to adapt them to receive visits from insects that can benefit them by depositing the pollen in the right place, and to shut out other insects that might rob them of their honey without rendering them service in turn. It is interesting to notice, also, that parallel with these modifications in the shapes of the flowers, there have resulted corresponding modifications in the structure of insects. Certain insects and certain flowers may almost be said to exist for mutual benefit. This subject opens most extensive fields for intensely interesting study. The present limits allow mere mention to be made of it. In the season of the flowers take every opportunity to watch insects visiting flowers. Write out an account of what you observe.[1]

[1] See Darwin's "Self and Cross Fertilization of Flowers"; Sir John Lubbock's "Flowers, Fruits, and Leaves"; and Weed's "Ten New England Blossoms and Their Insect Visitors."

24. *The fruit and seed.* — The entire ovary, together with such parts of the flower as become united with it, develops into the *fruit*. Each ovule develops into a *seed*, which is the end for which the plant exists. For the study of the different kinds of fruits and seeds, consult Gray's "School and Field Botany," pp. 117–128.

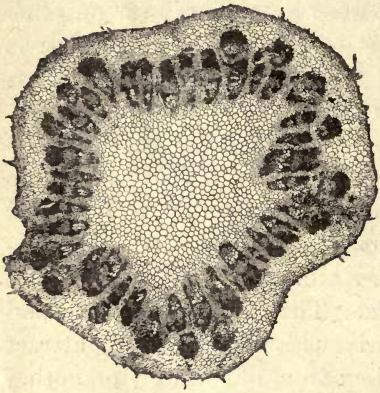

FIG. 4. — Transverse section of stem of a Burdock. (× 35.)

25. *The stem.* — Make an examination of the general construction of the stems of the Elder, Willow, Maple, Castor-oil Plant, House Geranium, Burdock, etc. With a sharp knife cut across the stems near their tips. Moisten the cut ends, and examine their structure under a magnifying glass. At the center is *pith;* in some stems of rapid growth the pith has parted and the stem is hollow. Outside of the pith is a ring of wood, and outside of the wood is the bark.

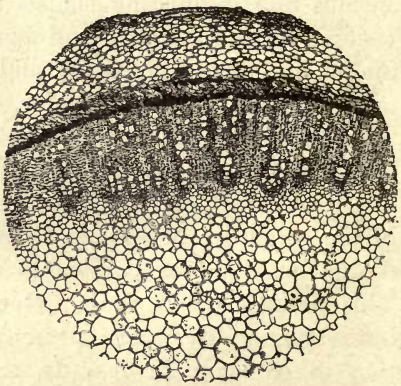

FIG. 5. — Part of transverse section of present year's growth of stem of Basswood. (× 35.)

Cut through stems of trees where they are of considerable size. Use a magnifier, and observe several rings of wood in place of the single ring in the young shoot. In general one ring of wood is formed each year.

Examine prepared microscope slides of the above or similar plants under the low power of the compound microscope. Also, if possible, examine a number of photomicrographs of sections of the same plants. (See Figs. 4, 5, and 6.) The arrangement of the wood in complete circles about a centrally situated pith or in bundles placed in a circle is characteristic of the Dicotyledonous Angiosperms.

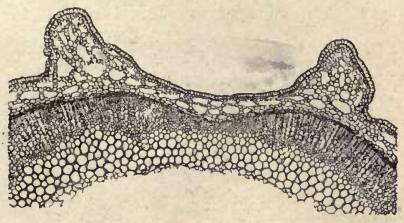

FIG. 6. — Part of transverse section of stem of *Mimulus ringens*. (× 35.)

26. *The root.* — Cut across the root of the common Burdock. Compare its structure in cross section with the structure of the stem of the same plant. Are the bundles of woody fibers situated the same as in the stem? The arrangement here observed is the rule for roots of this class.

27. When the trunk of a tree divides and subdivides until it is lost in the branches, it is said to be *deliquescent*. When the trunk rises straight up as one shaft, the tree is said to be *excurrent*. Make a list of all the deciduous trees with which you are acquainted, dividing them into deliquescent and excurrent trees.

The Monocotyledonous Angiosperms.

1. Raise seedlings of Indian Corn, Oats, Wheat, and Canary Grass in moist sawdust and in earth. Observe that one leaf only shows itself at first, and is followed later by a second. From this characteristic the Monocotyledons are named. Continue this observation until the seedlings have attained considerable size.

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2. Remove a plant of each kind from the earth. Wash the roots and examine them. Do any of these plants have taproots? Examine the roots of full-grown specimens of these plants as they grow in the field if possible; if that is not possible, those that have been preserved entire. Do any of these plants have roots that originate above the ground? Do these roots serve any purpose other than the usual one of supplying nourishment to the plant? Examine the youngest roots of the seedlings for root hairs.

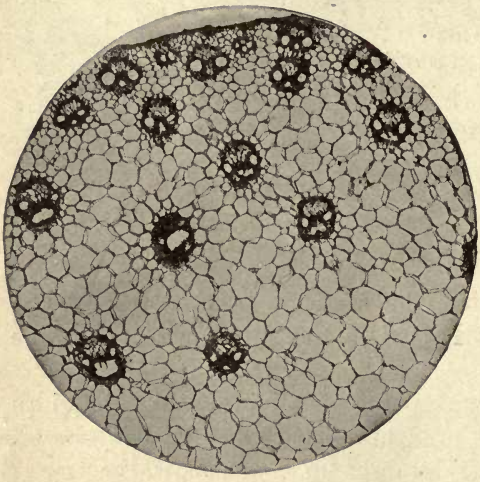

FIG. 7. — Transverse section through upper part of a Cornstalk, as seen under low power. (× 35.)

3. Cut across the stems of Indian Corn, different Lilies, Palm, Canna, and Asparagus. Examine the cut ends with a magnifying glass. Notice that the bundles of the woody fibers are scattered more or less irregularly through the stem. This is, in general, characteristic of the Monocotyledons, or Endogens.

With a razor or scalpel make thin, transverse sections. Do not try to get complete sections across the stem. Small pieces will do, but they must be very thin. Mount in water, cover with a cover glass, and examine under both low and high powers of the compound microscope, and compare with Figs. 7 and 8. Make also thin longitudinal sections of the Corn, and examine them for vessels whose walls are pitted; also for vessels whose walls are composed

of fibers wound in spirals; also for vessels whose walls are supported by rings at intervals. With a little patience all of these vessels may be found. These vessels constitute the principal portions of the wood of the stem. The markings observed are thickenings to give strength to the cell walls and to the stem.

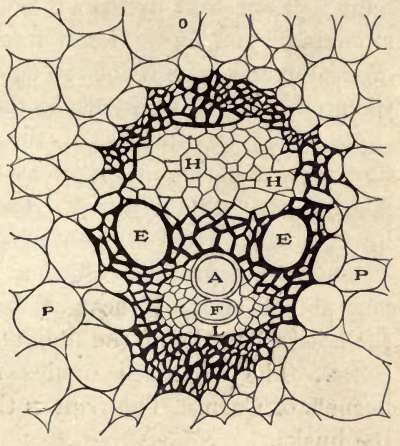

FIG. 8. — Fibrovascular bundle of Indian Corn, *Zea mays*. Transverse section, as seen under high power. *O*, *P*, *P*, cells of the ground parenchyma. The tissue represented by thick dark walled cells is the bundle sheath; *E*, *E*, pitted vessels; *F*, an annular vessel; *A*, spiral vessel: *L*, empty space produced by the tearing apart of the tissues in consequence of rapid growth; *H*, *H*, sieve tissue constituting the bast or phloëm portions of the bundle; *E*, *E*, *A*, and *F* are the main vessels of the xylem. The lower part of the figure was situated towards the center of the stem. (× 500.)

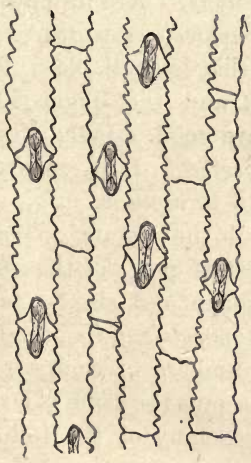

FIG. 9. — Epidermal cells and stomata of Corn.

4. Examine the veining in the leaves of Corn, Lilies, Palms, Canna, Orchids, Wandering Jew (*Tradescantia*), and various grasses. Represent by drawings as many types of parallel veining as you find. Parallel veins are characteristic of the Monocotyledons.

5. Examine under the compound microscope bits of the epidermis from both surfaces of each of the above leaves for stomata. On which side of the leaf are they more abun-

dant? Represent by drawings as many different types of stomata as you find. Each figure should show a number of the superficial cells of the epidermis and the position of the stomata with reference to these cells.

6. Study the flowers of the Indian Corn. The male flowers are borne in *spikes* at the very top of the plant. They constitute the *tassel*. The female flowers are borne lower down. Each filament of *silk* is the *style* of a flower. When pollen grains are brought in contact with the stigmas at the ends of these styles, they send minute tubes the entire lengths of the filaments into the ovules at their bases. The fertilized ovules mature into the seeds — kernels of Corn. The *fruit* is the entire ear of Corn with the husks.

Is Corn *anemophilous* or *entomophilous?* Are its flowers *perfect? Complete?* Is the plant *monœcious* or *diœcious?*

7. Study the flower of any Lily that is available. The Trillium, Wild Orange-Red Lily, and the Tiger Lily are good. Is the flower *perfect?* Is it *complete?* Is it *regular*, *i.e.*, are all the organs in each set of parts of the same shape and size? Is it *symmetrical*, *i.e.*, are the numbers of each set of organs the same? Draw as many of the following parts as you find: a *sepal*, *petal*, a *pistil* showing *ovary*, *style*, and *stigma*, a *stamen* showing *filament*, *anther*, and *dehiscence* of anther. Show by a figure a cross section and a longitudinal section of the ovary. (See Fig. 10.) Is the flower you are studying

FIG. 10. — Transverse section of ovary of Orange-Red Lily. (× 35.)

adapted to fertilization by the wind or by insects? Give reasons for your answer.

8. Examine the flowers of as many Orchids as possible. State for each one whether it is *perfect*, *complete*, *regular*, *symmetrical*, or not. Any extended study of the Orchids is too difficult for beginners. The great variety in colors and shapes among the Orchids is believed to be the result of variations to adapt the flowers to fertilization by particular insects, and to protect them from other insects that would rob them of their honey, without rendering any compensating service in the way of depositing pollen of other Orchids on their stigmas.

The Gymnosperms.

1. Examine various Pine and Spruce trees as they grow, selecting both old and young trees for study. Are these trees excurrent or deliquescent? Is the arrangement of the branches alternate, opposite, or in whorls? Make lists of all the evergreen trees with which you are acquainted, stating whether they are deliquescent or excurrent, and what the arrangement of the branches is.

2. Draw diagrams to represent accurately the lengths of the *needles*, or *leaves*, of as many different kinds of Pines and Spruces as you can find; also another set of diagrams to represent in outline these leaves as seen in cross section. Count the number of leaves in each little bundle for each different kind of Pine. Is the number the same in all the bundles of a given species? Does the number differ in different species? Would the number of leaves in the bundles help to determine the species of the Pine? Describe any difference you may notice in the color and surface of the leaves of different species of Pine.

Describe the arrangement of the leaves on the branch

of the Spruce. Is the arrangement the same on all the different kinds of Spruce you can find? Would the arrangement of the leaves help to distinguish the different kinds of Spruce trees?

Consulting Gray's "Manual of Botany," determine the names of all the different kinds of Pine and Spruce trees you can find.

3. With a hand lens notice the rows of stomata running lengthwise of the leaves. What purpose do stomata serve? Tear off bits of the epidermis and examine the stomata under the compound microscope. Draw them as seen under both low and high powers.

4. In May or early June find Pine trees bearing little cones clustered about the *base* of the new growth at the ends of the branches. These are the *staminate* or *male* flowers. Continue to watch these flowers until they shed their pollen. Observe in what profusion it is produced, and how it is carried by the wind to long distances. Why is it necessary that anemophilous flowers should bear such an abundance of pollen? Examine the stamens of which the male flower is composed under a magnifier and under the low power of the compound microscope. Find the *pollen sacs*. Are they borne on the upper or under side of the stamen? How do they open? Draw a stamen, showing the pollen sacs and their dehiscence. Examine some of the pollen grains under both low and high powers. Draw one.

5. Also in May or June find small pinkish cones near the *tips* of the new growth at the ends of the branches. Dissect one of these cones, noticing that it is made up of very thin leaves and of thicker ones that bear *naked* ovules. After the ovules have been fertilized, the leaves composing the cone shut together and protect the fertilized ovule while it is developing into the seed.

Are the ovules in the Angiosperms naked? The word

Angiosperm, roughly translated, means *seed in a vessel.* Gymnosperm means *naked seed.*

The thick leaves that bear the ovules are called the *carpels.* Where on them are the ovules borne? Is the shape of the pistillate flower adapted to catch pollen that is being borne about by the wind? Do you think that either the staminate or pistillate flower would attract insects because of its color or odor?

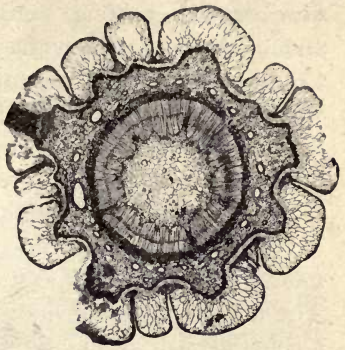

FIG. 11.—Transverse section of stem of Scotch Fir at close of second year's growth. (× 35.)

The fertilized ovules mature into seeds in the autumn of the second year. Secure some of the ripened cones before the seeds have dropped out. Draw one of the seeds. What do you think is the use of the winglike appendage on the seed?

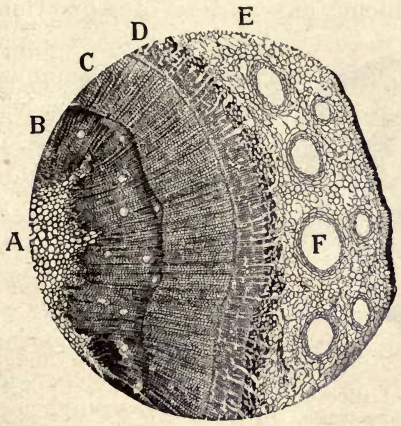

FIG. 12.—Part of transverse section of stem of White Pine during second year's growth. (× 35.) *A*, pith; *B*, wood of first year's growth; *C*, wood of the second year in process of formation; *D*, the cambium layer where the new growth originates; *E*, the bark; *F*, pitch ducts.

6. Cut across a Pine shoot of the present season's growth. If the material has been in alcohol long enough to dissolve out the pitch, it will be pleasanter to handle. Compare the arrangement of the pith, wood, and bark with the stem of an Angiosperm. Counting the

new growth as one, count back five internodes of the stem. Make a transverse section of the fifth internode. Count the number of annual layers of wood. Repeat with other internodes. How do the numbers of annual layers compare with the numbers representing the internodes? How could you tell the age of a given part of a Pine branch without cutting it?

7. Examine prepared microscope slides and photomicrographs of cross sections of Pine and Spruce stems. The arrangement of the wood in a complete circle about a central pith is the rule in the Gymnosperms.

THE FLOWERLESS PLANTS.

The Ferns.

1. Examine entire plants of as many of the following Ferns as may be convenient: any variety of Adiantum, Asplenium, Aspidium, Polypodium, Osmunda, Pteris, and Onoclea. Do this in the field, if possible; otherwise in the laboratory.

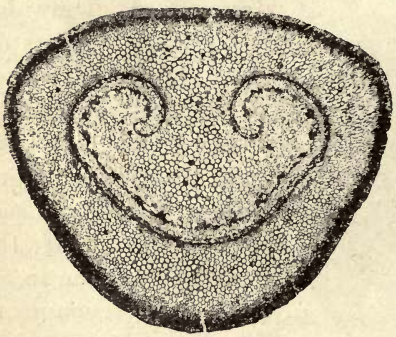

FIG. 13. — Transverse section of stipe of Cinnamon Fern, *Osmunda cinnamomea*. (× 35.) The curved figure is the fibro-vascular bundle.

Only the leaves rise above ground. Observation of the leaves as they uncoil in the spring should be made. The large underground portions are the stems, here called *rhizomes*. Branching from these are small fibrous *roots*. In removing the specimens from the ground, be careful to injure the rhizomes and roots as little as possible. Compare the rhi-

zomes of the different specimens. Cut transversely across each rhizome and examine the cut end with a magnifier. Make a sketch of each. The arrangement of the bundles of woody fibers, *fibrovascular bundles*, and the bundles of dark colored hardened woody tissue, *sclerenchyma*, form characteristic figures in the cross sections.

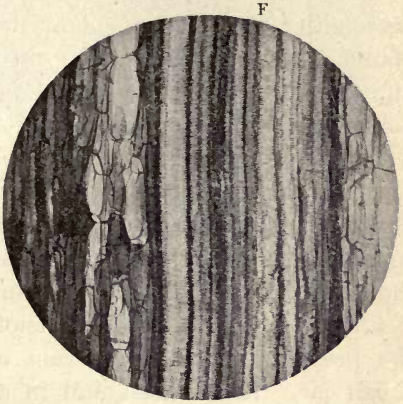

FIG. 14. — Vertical section of stipe of Cinnamon Fern, *Osmunda cinnamomea*, showing the fibrovascular bundle, *F*, in longitudinal section. (× 35.)

2. Examine the leaf or *frond* of an Aspidium Fern. It is supported by the *stipe*. It is *compound*, the *pinnæ* branching off from the *rhachis* or backbone of the frond, these in turn being divided into *pinnules;* in some species there are still further divisions.

Make a sketch of the entire frond, showing the venation on some of the pinnules. Is the leaf netted-veined or parallel-veined? Draw the back of one pinna, showing the arrangement of the *fruit dots* or *sori*. Cut across the stipe and examine the cut end with a magnifier. Repeat these observations with a frond of Adiantum. In Aspidium and Adiantum do all of the fronds bear sori? How is it with the other available species of Ferns? Find fruiting forms of as many other Ferns as possible, and make a comparison of the manners in which the sori are borne. Are they covered with a distinct *indusium*, as in the Aspidium, or is the indusium formed by the folding back of the edge of the leaf, as in Adiantum? Is the indusium lacking in any specimens?

Scrape off one of the sori upon a microscope slide and examine under the low power of the compound microscope. Notice the *spores*, which are borne in *spore cases* or *sporangia*.

3. We here meet with spores for the first time in descending the scale of plant life. The Ferns and the plants below them produce no seeds. Seeds, in the higher plants, result from the fertilization of ovules by pollen grains. Seeds grow directly into ordinary plants when the conditions are favorable. Spores result from cell division. They contain no embryo and do not grow into ordinary plants. The alternation of generations is very distinct in the Ferns. The ordinary Fern plants are the *sporophytes* or plants producing spores.

4. Spores grow by cell division. Sow Fern spores of the previous year's production on sand and cover with a bell jar. Keep moist and in a warm, light place, but not in direct sunlight. Study the growth by cell division by examining from time to time under the microscope, both low and high powers, the green growth on the sand that soon becomes just visible to the naked eye. These growths are the *protonemæ*. If the conditions are favorable, some of the *protonemæ* will develop in six or eight weeks into heart-shaped *prothallia* less than half an inch in diameter. The *prothallium* is the gametophyte form of the Fern, *i.e.*, the form that bears male and female cells which unite to produce again the *sporophyte* form or the plant. The more minute study of the gametophyte is best reserved for later work. It is well for the student here to see the prothallium and to have his attention called to the *antheridia*, or aggregations of cells which produce the *antherozoids*, or minute male cells, the male *gametes*, and to the aggregation of cells, the *archegonia*, that produce the *oöspheres*, or female cells, the female *gametes*. The male cells have the power of motion. At their ma-

turity they swim, when the prothallium is wet with rain or dew, to the *oöspheres*, enter and unite with them. An *öospore* is the result of this union, and this oöspore grows into an ordinary Fern plant. If prothallia are not produced by the culture on moist sand, they may often be found on the soil or pots in which Ferns are cultivated. A neglected fernery is quite sure to yield specimens.

After a Fern plant has once started by this mode of reproduction, it lives many years. The stem is usually wholly underground, only the leaf rising above ground.

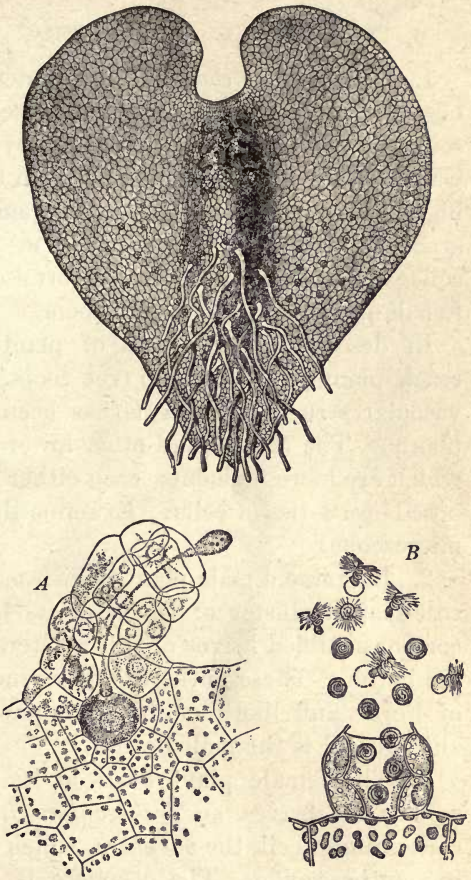

FIG. 15. — Prothallium of a Fern, exhibiting the reproductive organs. At the sinus of the heart-shaped film are to be seen the archegonia, one of which, more highly magnified, is displayed in section in *A*. *B*, an enlarged antheridium, with escaping antherozoids. (Luerssen.)

5. Try to identify the common Ferns of your neighborhood by analyzing with the help of Gray's "Manual" or Underwood's "Our Native Ferns and their Allies."

The Mosses.

1. *Polytrichum commune* is decidedly the best Moss to begin with on account of its large size and common occurrence. It is abundant everywhere by the roadside and in waste places. The plants are from three to eight inches high. The ordinary plant is the gametophyte, *i.e.*, there are male and female plants. The former bear motile cells, which find their way to certain cells borne on the female plants and unite with them.

In descending the scale of plant life we here first reach plants that have no true roots. A true root has a vascular structure, such as has been seen in the higher plants. The Mosses and other lower plants have *rhizoids*, which are mere filaments, each either a single cell or composed of a series of cells. Examine the rhizoids under the microscope.

2. Examine a male plant, which may be known by the rose-shaped cluster of leaves at its top. In the cells of certain modified leaves of this cluster, minute *antherozoids* are borne. These antherozoids resemble the antherozoids of Ferns, and like them have the power of motion. The antherozoid is the male *gamete*.

3. The female plant bears at its very top, concealed among the leaves, an *archegonium*, *i.e.*, a cluster of cells containing a cell, the *oösphere*, which is capable of receiving antherozoids. The oösphere is the female gamete. The union of the *antherozoid* with the *oösphere* produces an *oöspore*. The oöspore is raised up above the top of the female plant by a very slender stalk, the *seta*, and develops there into the sporophyte form of the plant. This remains fixed here until it has matured its *spores*.

4. The enlarged top that develops on the female plant is a *sporangium*. Examine and draw some of the *spores*

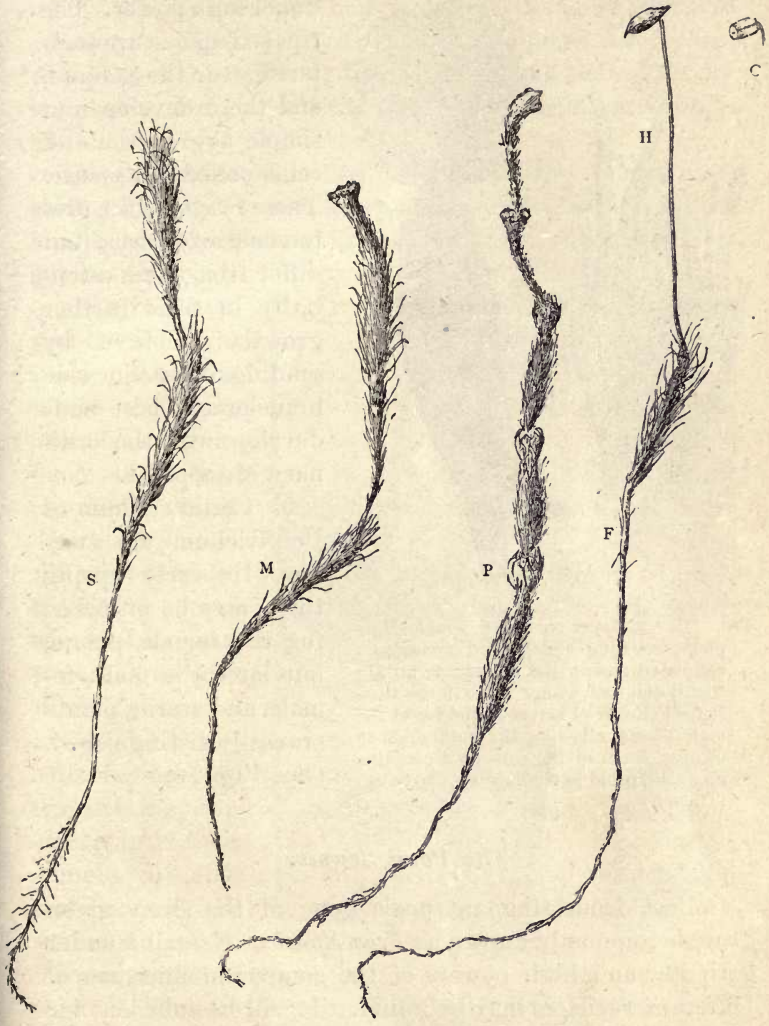

FIG. 16. — *Polytrichum commune*. *S*, sterile plant; *M* and *P*, male plants; *F*, female plant; *H*, seta; *C*, sporangium.

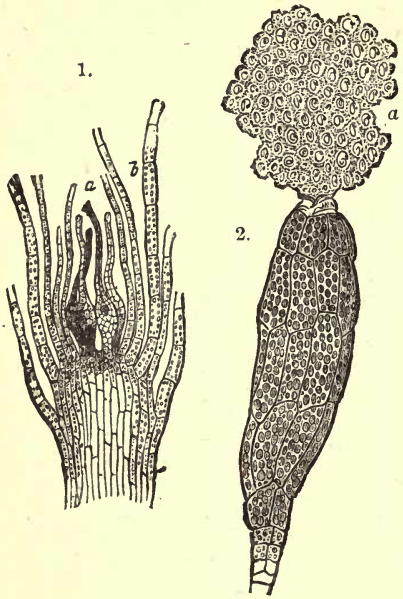

FIG. 17. — 1, Upper part of a female Moss plant, showing club-shaped archegonia concealed among the leaves; 2, an antheridium, such as are borne in the rose-shaped cluster of leaves at the top of the male plants, allowing the antheroids to escape. Each of the cells at *a* contains an antherozoid in a gelatinous covering. (Thomé.)

under high power. The ripened spores are scattered over the ground, and there develop into simple aggregations of cells, called *protonemæ*. These resemble the protonemæ of Ferns, but differ from them essentially in their further growth, which is by sending off *buds* or side branches. These buds develop into the ordinary Moss plant.

5. Certain plants of Polytrichum are sterile. In early spring these may be mistaken for the female plants, but later the male, female, and sterile plants are easily distinguished. (See Fig. 16.)

The Pond Scums.

Collect from stagnant pools some of the slimy green growth commonly known as *Frog Spittle*. Examine under both low and high powers of the compound microscope. Different varieties may be found. It will be sufficient for the present purposes if any variety in the conjugating condition is obtained, as these plants are to be studied more minutely later. Material in the conjugating condition that has been preserved in formalin or alcohol may be

used. Figure 18 shows one species of the pond scums in suitable condition for this study. The plant is a *thallus*. A *thallus* is the name applied to any plant that does not have roots, stem, or leaves. All such plants are *Thallophytes*.

The plants are one celled. They multiply by cell division. The divisions take place at right angles to the length of the cells, and, as the cells are covered with a gelatinous coating, they hold together and form long threads. There must, however, be some organic difference in the make-up of the cells of different threads, for, at the proper season of the year, the cells of one thread send out little tubes to the cells of some other thread lying near, and empty their cell contents into the cells of the second thread. The contents of the two cells mingle and form a *zygospore*. This becomes encased in a comparatively thick coating, *i.e.*, it becomes *encysted*, sinks into the mud at the bottom of the water, and preserves the life of the

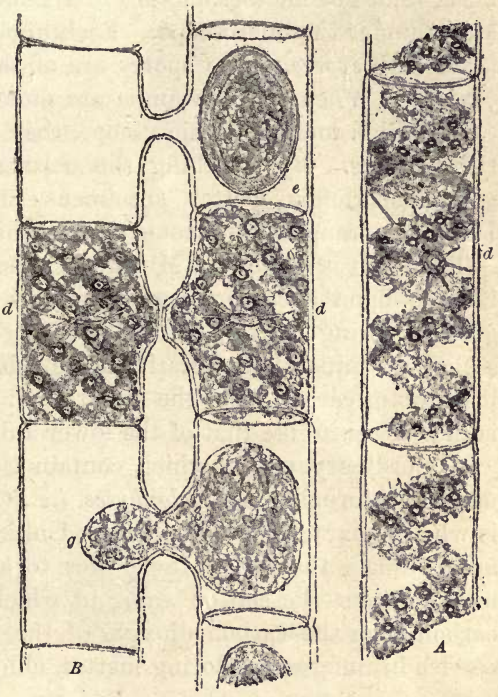

FIG. 18.—Spirogyra. *A*, vegetative cells; *B*, cells conjugating. (× 480.)

plant until the following season. It then develops by cell division into a new thread of the ordinary sort.

The Molds.

Keep pieces of moist bread under bell glasses until a white growth develops on them. Allow this to mature; the maturity will be indicated by the formation of little black knobs of microscopic size. Examine some of these knobs under the microscope. Each knob is a *sporangium* filled with *spores*. The spores are of the type known as *gonidia*. When ripe sporangia are mounted in water for examination under the microscope, they burst and scatter their spores. By watching the cultivation and taking young sporangia, better specimens may be obtained. Draw a sporangium and some of the spores.

The plant is one of the Mucors. It is a *saprophyte*, *i.e.*, it lives upon decaying organic matter. It contains no green coloring matter, chlorophyl, and has no power to assimilate mineral matters from the substratum on which it grows or carbon from the air around. Its mode of life is in a measure like that of the lower animals.

All ordinary plants which contain the green coloring matter, chlorophyl, are *holophytes*, *i.e.*, their mode of life is wholly characteristic of plants. Unlike the saprophytes and animals they have the power to assimilate mineral matters from the soil or water in which they grow and carbon from the carbon dioxide of the air. This power resides in the green coloring matter, chlorophyl.

Protococcus.

1. Obtain some of the green incrustation which is so conspicuous in wet weather on old trees, fences, and walls. It is *Protococcus*. Examine under high power. It is a

one celled plant, multiplying by cell division. Study and draw the little groups of cells that, for a time, cling together. (See Fig. 19.) The coherence between the different plants of these groups is very slight, so that the groups never become very large.

2. Put some of the bark, bearing Protococcus growth, in a glass of water and set in a warm, sunny place. Examine drops of water, obtained with the help of a camel's hair brush from the surface of the bark, daily, for minute colorless oval organisms like Fig. 20, *b*, which dart about rapidly.

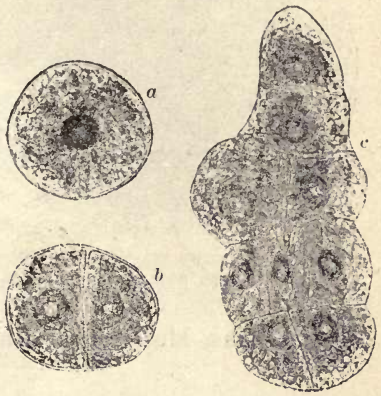

FIG. 19. — Protococcus, showing the multiplication of the plant by cell division. *a*, single plant; *b*, plant dividing into two; *c*, group of plants that have resulted from repeated divisions of a single cell. (× 480.)

They are *zoöspores*, *i.e.*, animal-like spores. At first glance one would not suppose there was any connection between the moving animal-like organisms and the cells of Protococcus. Nevertheless these moving organisms are not animals, but are one stage in the development of the plant. They have resulted from the division of the cell contents into a number of parts. Their motion, which will be studied later, is produced by alternate con-

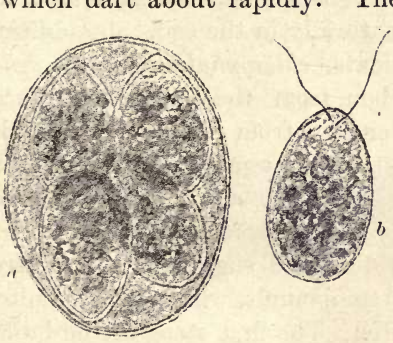

FIG. 20. — Protococcus. *a*, plant preparing for division into four large motile cells; *b*, one of the large motile cells, showing the cilia.

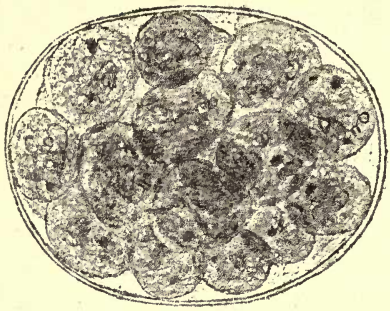

FIG. 21. — Protococcus. A cell preparing to divide into numerous small motile cells.

tractions and expansions of the two *cilia* which each bears at one end. It will be very difficult for the beginner to see these cilia. Special means for detecting them are given on page 86. A study of these moving forms helps to a better understanding of the motile antherozoids of the Ferns, Mosses, and other higher plants.

Plants and Animals.

Plants are, in general, characterized by the possession of a cellulose cell wall. Through this wall solutions of nutrient materials pass by osmosis. These nutrient materials are simple in their nature, consisting mainly of mineral salts that form naturally in the soil. In addition to these dissolved nutrients, *chlorophyl-bearing* or *holophytic* plants obtain carbon from the carbon dioxide of the air. The radiant energy from the sun effects the changes which convert these inorganic substances into living *protoplasm*, which is the life and essential part of every living cell. *Chlorophyl-less* or *saprophytic* plants obtain their carbon from dissolved sugar and their nitrogen from other organic compounds, which have resulted from previous forms of life. The first steps of the building-up processes have already taken place, and the saprophytic plants are not dependent on the sunlight. Plants, in general, are not capable of motion in the ordinary sense, but some of the lowest forms and the reproductive bodies of some of the more highly organized plants are,

as we have seen, capable of moving independently. Plants excrete water, carbon dioxide, and oxygen, but have no special organ of excretion.

Animals are characterized by the entire lack of cellulose in their cell walls. Their nutrition is by the digestion of somewhat complicated organic substances that are taken into the animal through a mouth, which may be only temporary, but is usually permanent. The waste matters are removed from the organism through definite organs of excretion, which also may be temporary, but are usually permanent. Independent locomotion also characterizes animals, though some live permanently attached to fixed supports.

The Protista.

There are certain organisms in which these characteristics that distinguish plants from animals are so combined that the highest authorities do not undertake to say whether the organism is a plant or an animal. To these organisms the name *Protista* has been given. To obtain an example of these organisms, allow water weeds to go to decay in a vessel of water. Examine some of the water from time to time under high power until organisms resembling Fig. 22, *e*, are obtained. This

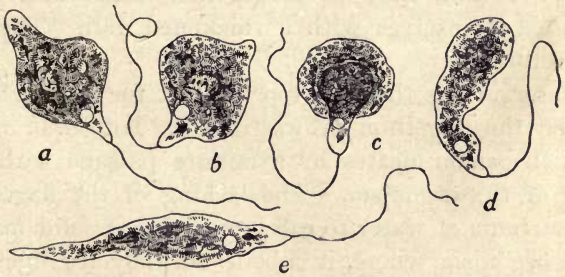

FIG. 22. — *Euglena viridis.* *e*, the normal form; *a*, *b*, *c*, *d*, forms going through the Euglenoid movements. The clear circular space seen in each figure is a contractile vacuole; the dark spot between the contractile vacuole and the anterior end is the eye spot. (× 480.)

organism is *Euglena viridis*. The body is several times as long as wide, and tapers towards both ends. By peculiar contractions the organism executes movements which are so peculiarly characteristic that they are known as *Euglenoid movements*. Besides these motions, Euglenæ make active, darting movements from place to place.

1. Hunt for forms that are executing the Euglenoid movements. Study the changes of form, and draw Euglenæ in three or four typical positions.

2. Study Euglenæ in active motion. How is the motion produced? Look for a *flagellum*, a very fine thread, at one end, and recall what was said about the motile forms of Protococcus. The beginner will find difficulty in seeing the flagellum. If it cannot be seen in the living organism, run iodine solution under the cover glass, and watch the Euglenæ as they die. Is the flagellum on the anterior or posterior end?

3. Examine a fresh mount of living Euglenæ for chlorophyl. In what portion of the organism do you find it? Is it found in one or several *chlorophyl bodies?*

4. Near the anterior end notice a small, red spot. This is known as the *eye spot*, but there is no reason for supposing it to be an organ of sight.

5. Try to find *encysted* forms, *i.e.*, forms that have surrounded themselves with a thickened wall. The cell wall is cellulose.

6. Observations that are too difficult for the beginner show that the flagellum grows from the bottom of a hollow which communicates by a minute passage with the interior of the organism. The lashing of the flagellum causes currents of water to carry particles of solid matter into the organism, where, it is believed, they are digested.

7. The possession of a cellulose wall in the encysted condition, and the occurrence of chlorophyl would place Euglena among plants; the Euglenoid movements and

the taking in of solid food through a permanent mouth would place it among animals. There are still other characteristics which are too difficult for observation by the beginner, some of which would place Euglena among plants, while others would place it among animals.

Animal Forms.

A consideration of a few of the lowest forms of animal life will help the beginner to a better understanding of the lowest forms of plants, and particularly to a better understanding of the motile forms of plants. The pupil will also be better prepared to understand the theory of evolutionists that all life on the earth has developed from the same original simple forms, plants being the result of variations in development along one line, animals of variation along another line. This consideration must be very brief and superficial.

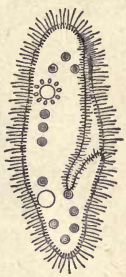

FIG. 23. — Paramœcium. The figure represents the organism only in outline. The circle in the lower part represents a contractile vacuole in a state of rest. The circle in the upper part, surrounded by dots, represents a contractile vacuole in the act of contracting to expel waste products. The series of dots shows the general movement of food particles within the organism. The whole cell has a granular appearance, and these details can be seen only by careful observation. (× 480.)

Paramœcium. — The same vessel of decaying water plants that furnished the Euglenæ has probably also produced *Paramœcia* or *Slipper Animalcules.* Study these under high power, comparing with Fig. 23. Notice particularly the fringe of minute hairs, or cilia, whose lashings produce the movements of the organism.

Amœba. — Amœbæ have also probably been produced in abundance in the vessel that has provided the Euglenæ

and Paramœcia. With a pipette transfer to a microscope slide repeated portions of the sediment from the vessel until good specimens of Amœba are found, using the high power, or with a camel's hair brush remove the Amœbæ from the surface of some of the larger pieces of débris taken from the vessel. A little care must be exercised at first in searching for them, or they will be overlooked. They are so colorless and transparent, like little masses of clear jelly, that only careful watching will enable the beginner to make them out at first. After they have once been recognized, there will be no trouble.

FIG. 24. — Amœbæ. The clear spot in each is a contractile vacuole. Each contains particles of food in process of digestion; *a* is in the act of surrounding a food mass.

1. Observe a difference between the central portion of the organism and the portion around the edges. The latter is very clear and transparent; it is known as the *ectosarc*. The central portion has a granular appearance; it is called the *endosarc*.

2. Watch the motions of different specimens. Observe that projections of the ectosarc, *pseudopods*, are thrown out; after a time portions of the endosarc flow into these, and a movement of the whole organism is caused.

3. Search for food particles in the endosarc. These are easily distinguished from the protoplasm of the endosarc. Watch Amœbæ that are in active motion until

they are seen to surround food particles. Particles of powdered carmine may be introduced to serve as food. Observe also, if possible, the rejection of refuse particles from the body. These observations may require patient and continued watching, but will well repay a little effort.

4. Find Amœbæ which show *contractile vacuoles*. These are clear spots which may be seen suddenly to contract and then slowly to expand. It is believed that the contractile vacuole is an organ for the excretion of the liquid waste products. Euglenæ and Paramœcia also have contractile vacuoles.

5. The lack of cellulose in the cell wall, the taking of somewhat highly organized foods, the manner in which these foods are taken and the method by which the refuse is expelled from the body, the possession of contractile vacuoles, and the character of the movements place Amœba among the animals. It is the lowest form of animal life, and in observing it the pupil will obtain a very good idea of the appearance of simple protoplasm, which is believed to be essentially the same wherever it occurs, whether in plants or in animals.

I.

THE SLIME FUNGI.

The **Slime Fungi** (*Myxomycetes*) are mere masses of protoplasm without definite shape. In appearance they resemble some of the Protozoa so much that it is very difficult to distinguish them from the lowest forms of animal life. Their manner of living does not help to decide the question, for their nutrition is neither entirely holophytic nor holozoic, that is to say, neither entirely after the manner of plants, nor entirely after the manner of animals. They live in part by the absorption of solutions of decaying organic matter, *i.e.*, after the manner of saprophytic plants; in part, by the digestion of particles of solid matter that they have inclosed after the manner of the Amœba, the lowest of animals. So much do these organisms partake of the nature of both plants and animals, that they are classed as plants by some eminent scientists and, under the name of *Mycetozoa*, as animals by others equally as well qualified to judge, while still others evade the question by making a third kingdom, that of the *Protista*, in which these and other doubtful forms are placed. Because of these doubts, and because of the simplicity of their structure, the Slime Fungi are placed by themselves at the lowest point in the scale of classification.

The Slime Fungi vary in size from forms that must be studied with the microscope up to forms several inches in diameter, as in the large sulphur-colored forms known as *Flowers of Tan*, the *Æthalium septicum*. They creep about over the substratum on which they grow in a way which resembles alike the movements of Amœbæ and, as

Hofmeister has pointed out, the movements of protoplasm in the cells of the higher plants. These plants grow better in the dark than in the light, and Sachs has shown that they exhibit a marked irritability to the influence of light. The *Flowers of Tan* are favorable plants for study. These develop on piles of tan bark and on decaying leaves and bark during hot, sultry weather. They appear suddenly when the conditions of heat and moisture are favorable, and run through their course of existence within the space of a few days. If the conditions are changed, they disappear. If masses of the tan on which they have begun to develop are placed in the dark, the slime spots collect on the surface ; if strong light is allowed to fall on them, the spots creep down into the masses of tan. It is, however, only during the earlier, plasmode stage of their development that they exhibit this irritability to light. During the later stages of development, they flourish in strong light. Sachs has also shown that the Slime Fungi are influenced by an apogeotropic stimulation which causes them to ascend the stems of plants, or even glass plates placed vertically in the substratum on which they grow. Growths are thus easily obtained for microscopic study.

Recent theories attribute certain malarial diseases to species of the Slime Fungi which find entrance to the human blood through the medium of drinking water and there multiply in the amœboid condition. In the blood they are combated and eaten by the colorless amœboid corpuscles — the *phagocytes*. Victory by the phagocytes means recovery of health; victory by the Slime Fungi means death.

In their earlier stages these Slime Fungi form continuous, or nearly continuous, masses of protoplasm, without cell walls, without fixed shape, and without green color. They are whitish, colorless, or of a yellow sulphur color,

sometimes tinged with red. In the later stages of their growth rounded masses appear in the protoplasm, each of which develops a cell wall and becomes a resting spore. Toadstool-like elevations also appear which bear resting spores. The resting spores live after the moisture has evaporated, and in the form of a dry powder are scattered abroad by the wind until they strike some moist surface where the conditions are favorable for their development, when each spore is capable of growing into a new organism.

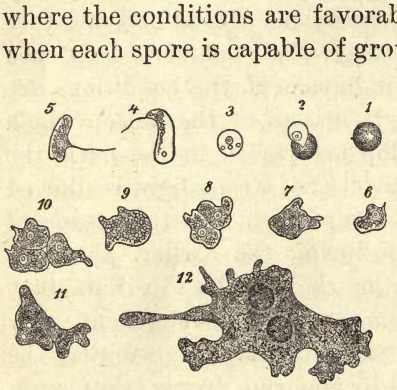

FIG. 25.—*Physarum album.* (From Sachs, after Cienkowski.) 1, spore; 2, emission of its contents; 3, the free contents; 4, 5, the same as swarm spore with one flagellum; 6, 7, the same after losing their flagella; 8, 9, 10, 11, fusion of amœboid forms; 12, a small plasmodium.

In the beginning of this growth, the spore develops into a motile Amœbalike form. These forms meet and flow together, forming the so-called *plasmodia*, which in some cases attain a considerable size. As the plasmodia increase in size, a true flowing movement takes the place of the amœboid movements which characterized the earliest motile forms. In some of the Slime Fungi ciliated swarm spores form. These move by a combined hopping, rotating, and creeping motion, as well as by amœboid movements. After a time the cilia are lost, and the forms which now become Amœbalike unite to form plasmodia. The earlier forms of the Slime Fungi also multiply by repeated divisions of the mass. There is no alternation of generations from sporophyte to gametophyte; the plant is the sporophyte. There are, then, five distinct stages in the existence of these organisms, as follows: *a.* The spore,

Fig. 25. 1. *b*. The contents of the spore become a naked mass of protoplasm, provided with a flagellum by means of which it moves, Fig. 25, 3, 4, 5. During this stage multiplication may take place by division. *c*. The organism loses its flagellum and becomes amœboid in character, Fig. 25, 6, 7. *d*. Two, or more frequently several, amœboid forms unite and form a *plasmodium*, Fig. 25, 8, 9, 10, 11. This moves and obtains its food, at least in part, as does the Amœba. *e*. The plasmodium secretes a cell wall and so becomes encysted. The cell contents then break up into spores. Figure 25, 12, shows a plasmodium preparing for these changes.

The Slime Fungi are to be looked for in the water, on the bark of trees, tan bark, decaying leaves or wood, and in similar locations. Piles of tan bark afford especially good ground to search for them.

References for Reading. — Parker's "Elementary Biology," pp. 49–55; Goebel's "Outlines of Classification," pp. 14–17; Carpenter's "The Microscope and its Revelations," pp. 563–565; Sachs' "On the Physiology of Plants," pp. 82–84, 429, 430, 613; Bennett and Murray's "Cryptogamic Botany," pp. 401–404; Strasburger, Noll, Schenck, and Schimper's "Lehrbuch der Botanik," pp. 264–266.

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II.

THE DIATOMS.

The **Diatoms** (*Diatomaceæ*) are of very common occurrence. Not less than ten thousand species have been described.

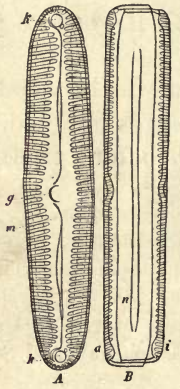


FIG. 26. — *Pinnularia viridis* Sm. *A*, valve view; *B*, girdle view (diagrammatic). *m*, raphe; *g*, central node; *k*, terminal nodules; *a*, outer and older valve; *i*, inner valve. (× 800.) (From Bennett and Murray, after Pfitzer.)

They occur in water, both still and running, salt and fresh, growing on the leaves and stems of aquatic plants, or attached to sticks and stones, or mingling with the mud at the bottom. They are brown in color, because of the coloring matter called *diatomin*, and are sometimes classed with the Brown Algæ for this reason. They also contain chlorophyl. Their exact position in the classification of plants is not easily determined, as they do not seem to be connected even remotely with any other plants. They are therefore given a place by themselves in the classification.

The Diatoms occur as isolated cells, or connected in filaments. The filaments sometimes partly separate, leaving the cells strung together by their corners, forming striking and characteristic patterns. Some forms grow on gelatine-like stems. Diatoms vary in size from forms that require a high power of the microscope to distinguish them to forms that are plainly visible under the one-inch objective.

None are large enough to be seen with the unaided eye. Some Diatoms resemble in shape certain Desmids, but the brownish color of the Diatoms distinguishes them at once from the bright green Desmids. Many species of the Diatoms are capable of independent movement from place to place. The manner in which the movements are accomplished is not well understood. One theory is that the motions are caused by currents of water, which pass through small openings in the organism, or perhaps by osmosis through the thin partitions of the cells. Another theory ascribes them to the contractions of the protoplasm, which protrudes through minute openings in the cell wall.

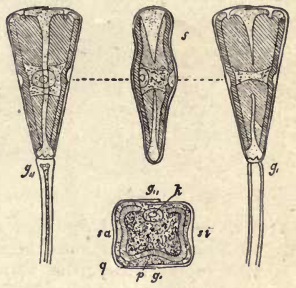


FIG. 27. — *Gomphonema constrictum* Ehrbg. *s*, view of *valves*; $g_{,}$, view of the girdle corresponding to the right; $g_{,,,}$ to the left margin of the valves; *q*, transverse section through the middle of the cell, showing with unusual distinctness the composition of the silicified cell wall of two halves, one overlapping the other (*sa*, the larger, *si*, the smaller valve); *k*, the nucleus; *p*, dense protoplasm; $g_{,}$, $g_{,,,}$, the two girdle surfaces. (From Bennett and Murray, after Pfitzer.)

The Diatoms are one celled plants. A plant cell may be considered as a closed or nearly closed box, whose walls are composed essentially of a substance called *cellulose*. All living cells are filled or lined with protoplasm, in which resides the true life of the plant. The protoplasm of a plant cell has been compared to a living snail, and the cell wall to the snail's shell. As the shell has been secreted by the snail, so the cell wall is secreted by the living protoplasm within. In the filamentous forms of Diatoms the cells are simply associated together, but are without organic connection. The association of unicellular organisms in filaments will be seen in some forms of Bacteria, in the Zygnemeæ, and the Desmids.

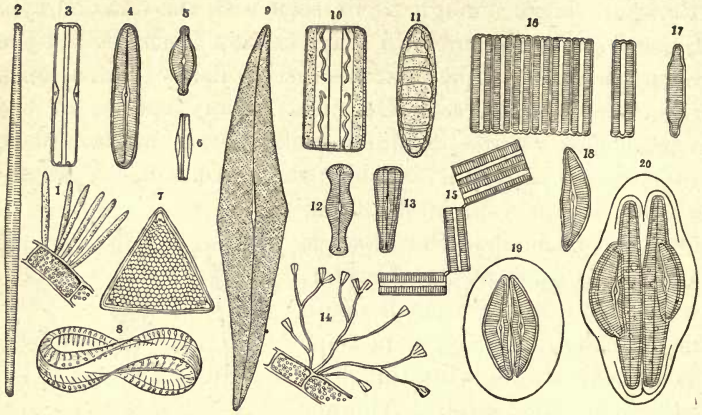


FIG. 28.—1, cells of *Synedra ulna* attached to a plant cell; 2, a single cell of *Synedra ulna* more highly magnified; 3, *Navicula liber*, side view; 4, *Navicula liber*, front view; 5, *Navicula tumida*, front view; 6, *Navicula tumida*, side view; 7, *Triceratium favus;* 8, *Campylodiscus spiralis;* 9, *Pleurosigma angulatum;* 10 and 11, *Grammatophora serpentina;* 12 and 13, *Gomphonema capitatum;* 14, *Gomphonema capitatum* on stalks attached to plant cells; 15, *Diatoma vulgare;* 16 and 17, *Fragilaria virescens;* 18, *Cocconema cistula;* 19, two cells of *Cocconema cistula* preparing to form auxospores; 20, the same after the auxospores have elongated and are preparing to throw off the old cases which are seen on the right and left. 19 and 20 show the cells enclosed in gelatinous sheaths. All of these figures are highly magnified. (Kerner and Oliver.)

The individual cells are commonly spoken of as *frustules*. The structure of these frustules is highly characteristic. The foundation of the frustules is cellulose, heavily laden with silica which has been deposited from the water in countless numbers of exquisitely delicate and interesting patterns. Each frustule is made up of two valves, one of which overlaps the other like the cover of a box. (Fig. 26, *B* and Fig. 27, *q*.) The junction of the two valves is called the *girdle*. The frustules inclose a mass of protoplasm containing granules bearing chlorophyl and others bearing the brown pigment that gives the prevailing color to the organisms.

If gatherings of Diatoms be treated with boiling nitric

acid, or sulphuric acid and potassium bichromate, the organic portions will be entirely removed, and the silicious shells will be left uninjured. These shells, as well as the living Diatoms, have been objects of great interest to microscopists at all times on account of the great variety of beautiful markings. The more delicate forms are also highly esteemed as test objects for microscope objectives. Besides the living forms there are numerous deposits of the silicious shells of Diatoms in various parts of the world. The accumulation of sediment formed by their successive production and death in the waters of oceans, lakes, and rivers gives rise to deposits that may attain considerable thickness, and these, by subsequent changes of level, may come to form parts of the dry land.

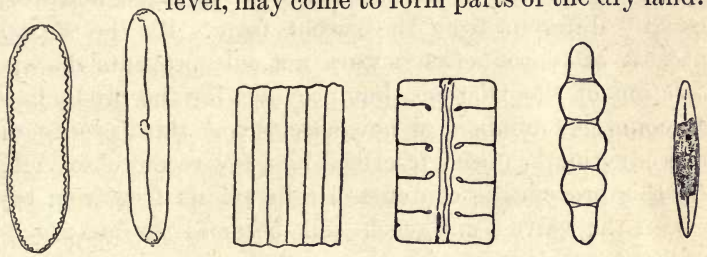


FIG. 29.—1, *Surirella constricta*, side view; 2, *Pinnularia viridis;* 3, part of a filament of *Fragilaria pectinalis;* 4 and 5, side and front views of *Terpsinoë musica*, the so-called musical Diatom; 6, *Navicula*.

Certain deposits in Norway and Sweden are known as Bergmehl (mountain meal). They are used by the peasants to mix with the flour in making bread. Fossil Diatoms are sold under various names as polishing powders, for which purpose they are excellent, and are extensively used.

Diatoms may be obtained for examination from these deposits, or the living forms may be secured by stripping the yellowish-brown coating from the stems of water plants, or by gathering the thin film of black mud from the bottom of springs, ponds, and streams.

Diatoms are reproduced both sexually and asexually. By the asexual process the cell divides lengthwise by the separation of its two valves. Each of the valves develops a new valve to mate itself, and after a time the two new cells separate entirely. The new valve always develops on the inside of its mate, and is therefore smaller. If this diminution were to continue indefinitely, the Diatoms would, of course, practically disappear in time.

The sexual process of reproduction is evidently designed to prevent this disaster. In this process the contents of individual cells are set free from between the valves and become zoöspores. These zoöspores unite in pairs, and the resulting zygospore or auxospore develops into a large form. (Fig. 28, 19, 20.) This new form is, however, usually different from the parent form. By the sexual process of reproduction nature not only prevents the extinction of the Diatoms, but provides for the production of countless numbers of new species. A third process of reproduction has been described by a few recent observers. By this process the contents of cells are set free from between the valves, and each cell becomes an auxospore without previous conjugation.

Although distinct sexual and asexual forms occur, the life history of these plants is not fully understood. The alternation of generations is by no means clear. The ordinary asexual forms may be potential gametophytes, or they may be sporophytes.[1]

References for Reading. — Bennett and Murray's "Cryptogamic Botany," pp. 419–426; Carpenter's "The Microscope and its Revelations," pp. 516–554; Goebel's "Classification of Plants," pp. 17–19; Strasburger and Hillhouse's "Practical Botany," pp. 210–213; Strasburger Noll, Schenck, and Schimper's "Lehrbuch der Botanik," pp. 273, 274.

[1] The pupil should be given gatherings both of recent and of fossil Diatoms for examination. He should also be encouraged to collect material for himself. The teacher can easily arrange a series of Practical Studies on any forms that are conveniently obtained in the locality.

III.

THE FISSION PLANTS.

The **Fission Plants** (*Schizophytes*) naturally fall into two classes:

CLASS I. THE BLUE-GREEN SLIMES (*Cyanophyceæ*).
CLASS II. THE BACTERIA (*Schizomycetes*).

CLASS I. The **Blue-Green Slimes** (*Cyanophyceæ*) are chlorophyl-bearing plants. They therefore belong to the Algæ, using this term in its broader sense. They differ so much, however, in life history from the rest of the Algæ that they cannot be brought into classification with them. On the other hand, they show certain resemblances in their structure and modes of development with the Bacteria. They agree with the Bacteria in forming resting spores, in multiplying by cell division, in not multiplying sexually, and in secreting heavy hyaline gelatinous envelopes. It therefore seems appropriate that the Blue-Green Slimes and the Bacteria should be considered by themselves. The Blue-Green Slimes also contain in addition to chlorophyl — the green coloring matter — a blue coloring matter — *phycocyanin*. This is another characteristic separating them from the rest of the Algæ. The two colors combined give the plants a bluish tinge.

No sexual reproduction is known to occur in this class. There is consequently no alternation of generations from sporophyte to gametophyte. The plant is the sporophyte.

Scattered through the protoplasm are granules that are supposed to partake of the nature of nuclei, though no true nuclei are found. The plants of this class occur

in greater or less abundance in the gatherings from stagnant pools and ditches and in masses on moist rocks. There are five orders in the Cyanophyceæ. They are the *Chroöcoccaceæ*, *Nostocaceæ*, *Rivularieæ*, *Oscillatorieæ*, and *Scytonemeæ*.

In the **Chroöcoccaceæ** the cells are enveloped in a transparent gelatinous covering. The cells are found singly, or associated in different small groups, which result from the repeated division of single cells. Groups of three are common. These plants occur as slimy growths in damp places and in stagnant water, usually associated with other kinds of plants. The two most common forms are *Chroöcoccus* and *Glœocapsa*. These are very simple organisms. They are distinguished from other organisms by the uni-

FIG. 30. — Glœocapsa, magnified.

formity in the distribution of the minute blue-green granules through the protoplasm and by their gelatinous envelopes. In Glœocapsa the envelope has two distinct layers, which in the older forms are quite dark, facts that serve to distinguish it from Chroöcoccus. The cells divide by partitions running in all directions through the parent cell and thus give rise to groups of cells.

The **Nostocaceæ** form filaments which distinguish them from other plants containing the blue-green coloring matter characteristic of this class. The filaments in some of the species are more or less coiled in gelatinous envelopes. The cells of the filaments are not uniform throughout, but there occur at intervals larger cells that receive the name *heterocysts*. There are three modes of reproduction.

First, by division of the cells in a direction transverse to the length of the filament. Second, by the formation of resting spores that develop into new filaments. Third, in a special way by the formation of what are called *hormogonia*. The parts of the filaments between the heterocysts escape from the gelatinous covering after it has become more or less decayed and dissolved. After a time each of these fragments becomes invested with a new gelatinous covering and develops into a new filament by the division of its cells.[1]

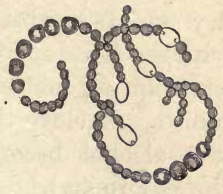


FIG. 31. — A Nostoc. *Anabæna flosaquæ* Fr. (×400.) (After Cook.)

The **Rivularieæ** are found as minute masses of dark blue-green color in sluggish streams and in standing water. The filaments radiate from the center of the mass. The masses are seldom more than one or two millimeters in diameter.

The **Oscillatorieæ** occur as a dark blue-green scum on the surface of stagnant water, about watering troughs, on wet rocks, on Lily pads, and in similar locations. Examined under the microscope, the filaments are seen to oscillate slowly from side to side, a phenomenon that has not as yet been satisfactorily explained. The plants multiply by

FIG. 32. — Oscillaria, magnified. A single plant in the vegetative condition. The filament has resulted from repeated transverse divisions of the cells.

the transverse division of the cells. Resting spores are also formed, which continue the existence of the plant in the dried state.

[1] The teacher might arrange a series of Practical Studies, involving the observation of these facts, on any species of Nostoc that is available.

OSCILLATORIEÆ. — PRACTICAL STUDIES.

1. Collect a considerable quantity of the dark blue-green plants from any of the above-mentioned locations, dry and pulverize it, and place it in a clear glass dish with some water for several hours. The water dissolves the coloring matter known as phycocyanin and becomes bluish. Remove the water, add strong alcohol, and boil. The alcohol becomes yellowish green by dissolving out the chlorophyl.

2. Mount a little of the fresh Blue-Green Slime in water, *i.e.*, place it on a microscope slide in a small drop of water and cover with a cover glass. Under both low and high powers of the microscope study the oscillations of the filaments. Notice the tendency of the filaments to radiate from a center.

3. Study the cells of a filament. Note the finely granular protoplasm and its uniform distribution in the cell. Compare a branch of Nostoc, noting the sizes of the cells and the positions of the heterocysts or enlarged cells in the Nostoc. Find short filaments of Nostoc that have broken off at the heterocysts to form hormogonia. Such filaments are frequently found in stagnant water. Draw part of a filament of Oscillaria and one of Nostoc, showing the characteristic structures.

4. Observe the gelatinous sheath inclosing the filament. This is much more distinct in some species than in others. In some species it is wholly wanting. In difficult cases it is best seen at the broken ends of filaments.

5. Notice the turgidity of the cells, *i.e.*, their swollen appearance, due to the fact that the internal pressure of the water that has been absorbed by the protoplasm is greater than the external pressure. This is best observed at the broken ends of filaments where the cell wall is bulged out by the internal pressure.

6. In each of two test tubes containing a small quantity of ordinary water place a little of the Oscillaria and set the two tubes in a sunny window, having first wrapped one of them in thick, opaque paper to shut out the light. All conditions are the same for the two tubes except the light. After a day or two examine. What conclusion do you draw as to the necessity of the light for the healthy growth of the plant?

7. Place a little Oscillaria in a test tube with ordinary water and set in a window. By its side place some of the Oscillaria in water that has been boiled to expel the carbon dioxide which is contained in all natural water. From time to time compare the plants in the two tubes. What conclusion do you draw as to the necessity of carbon dioxide for the healthy growth of the plant?

References for Reading. — Goebel's "Classification of Plants," pp. 20–23; Vines' "Text-Book of Botany," pp. 231–233; Bennett and Murray's "Cryptogamic Botany," pp. 426–449.

CLASS II. **The Bacteria** (*Schizomycetes*). — These plants are also known as *Fission Fungi*. That the Bacteria belong in this place in the classification admits of serious doubts. To find that they are related to any other group of plants is equally, if not more, difficult. Some authorities place them by themselves as a group of the *Protista*, — organisms that possess characteristics of both plants and animals. Others class them as undoubted *Fungi*, but they differ too much in their life history from the rest of the Fungi to be treated with them. Resemblances to the Blue-Green Slimes in their modes of reproduction by the transverse division of cells, and in the formation of resting spores to continue their life in time of drought, make it proper that they should be considered in this place. The plant is the sporophyte ; there is no alternation of generations.

The nutrition of the Bacteria is in general that of saprophytic plants, *i.e.*, of those that live on decomposing organic matter. Some forms live as parasites. This is the fact in the case of the forms which thrive in the living tissues of animals, producing disease. At least three species — *Bacillus virens*, *Bacterium chlorinum*, and *Bacterium viride* — are known to contain chlorophyl, and their nutrition must be in part or wholly holophytic, *i.e.*, like that of the green plants. *Bacillus amylobacter* also produces a substance which, when treated with a solution of iodine, gives a blue color which is characteristic of the reaction of starch. Starch is the product of chlorophyl-bearing plants. Some species live and multiply in solutions that contain no organic matter, a fact which tends to support the theory of evolutionists that the earliest forms of life were *Protista*, and that plants and animals have developed from these by gradual evolution in different directions, which have been determined by local conditions.

Many forms of Bacteria possess the power of moving from place to place. These motions are in some cases believed to be produced by the action of cilia; in other cases it is believed that they are caused by contractile movements of the protoplasm.

The ordinary mode of multiplication of Bacteria is by the transverse fission of the cell. In some cases the newly formed cells separate; in other cases they remain in contact, held together by a hyaline, gelatinous secretion, forming filaments of some length. Another mode of continuing the existence of the organisms, which obtains in some species when the conditions of nutriment and moisture are unfavorable for the fission of the cells, is by the formation of resting spores. These spores form in the center of most of the cells, one in each. They are the resting condition of the organism and possess much greater vitality than the cells. In the spore condition

the Bacteria may exist for indefinite periods of time, and will endure much higher temperatures than the ordinary forms. In this condition they are wafted about from place to place in the air. When they meet with conditions favorable to the life of the organism the spores develop into cells, which multiply by the usual process of fission.

Bacteria occur everywhere, accomplishing both good and harm. The air, in its purest condition, contains numerous spores. Putrefaction and fermentation of all kinds are brought about by the direct agency of these organisms. It is settled beyond dispute that many infectious diseases are caused by Bacteria. Other Bacteria are not only harmless but are believed to be essential to life in aiding in the digestion of the food. Some are profitably cultivated and sold to the makers of butter and cheese for producing desired states and conditions. Other forms are absolutely essential to the life of the higher plants in bringing about nitrification in the soil, thereby furnishing food materials for plants.

Bacteria exert a very important influence on the substances in which they grow. In the case of the pathogenic, or disease-producing Bacteria, by-products, known as *ptomaines* and *toxins*, are formed. These poisonous products are the active influences in causing the disease. These poisons have been isolated from the bodies of animals that have died of different diseases. When tried on animals known to be capable of taking these diseases, they are found to work with great virulence. Notable instances of toxins are the poisons produced by the Bacteria that cause the changes in fish, meat, and ice cream. It is fortunate, however, for man and animals that the products formed by far the greater number of Bacteria are not poisonous, so that the Bacteria which we are constantly taking into our systems with our food and water only in exceptional cases work

injury. Some putrefactive Bacteria act as organized ferments. The conversion of the sugar of milk into lactic acid by *Bacterium lactis* in the souring of milk, and the production of acetic acid from alcohol and oxygen by *Bacterium aceti* in the souring of wine, are examples. The nitrification of the soil already mentioned is still another example of the action of a bacterial ferment.

Various classifications of Bacteria have been proposed, but none are very satisfactory on account of the difficulties in the way of their study, and because of the still undeveloped state of bacteriology as a science. It is not yet settled that forms which are now generally considered as genera may not be different stages in the life history of the same species, so that the study of the morphology of Bacteria gives very indefinite results. It is, however, convenient to distinguish the different forms in a rough way, and the following names have been adopted: *Bacterium* denotes a short, thick, straight rod; *Bacillus*, a longer, slimmer, straight rod; *Leptothrix*, unbranched filaments in which the segments can usually be distinguished only after treatment with stains; *Micrococcus*, a small sphere; *Vibrio*, *Spirochæta*, *Spirillum*, coiled forms. De Bary illustrates the three principal forms by "a billiard ball, a lead pencil, and a corkscrew."

BACTERIA.—PRACTICAL STUDIES.

1. Mount a little of the *fur* from your teeth in a drop of water. Scrape the teeth just under the gums with a knife point. Place a little of the scrapings in a drop of water on a cover glass. Put another cover glass upon it, press and rub the two cover glasses together until there is a thin film on each. Mount by inverting one of the cover glasses on a small drop of water on a microscope slide. Examine with high power and find Micrococci,

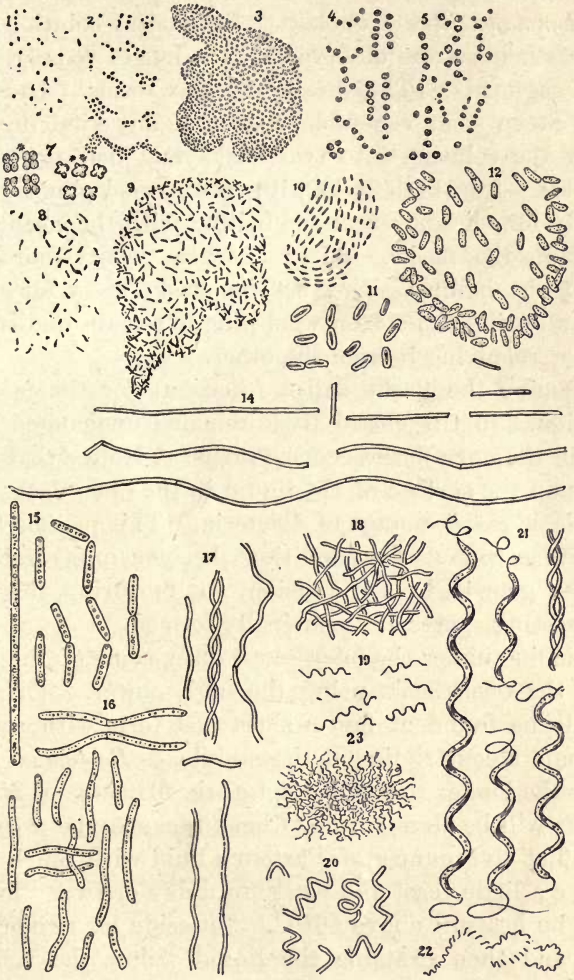


FIG. 33.—Forms of Bacteria. 1, 2, 4, and 5, Micrococci; 3, zoöglœa stage of Micrococci; 7, sarcina or packet forms of Micrococci resulting from successive divisions in different directions; 8, 9, and 10, zoöglœa stages of Bacilli; 11 and 12, forms of Bacterium; 14, Leptothrix filaments; 15 and 16, Bacilli and Spirilla, showing spores; 17, Vibriones; 18, 19, 20, and 21, Spirilla; 22, Spirochætæ; 23, zoöglœa stage of Spirochætæ.

Bacilli, and Spirilla. The comma-shaped forms resemble the *Comma bacillus* of cholera. Run iodine solution under the cover glass and observe that the longer rods are made up of segments. They are Leptothrix forms. Draw.

2. Steep some vegetable matter of any kind in water. Filter the solution into two flasks and boil for twenty minutes. Stop both flasks with cotton-wool plugs. After twenty-four hours repeat the boiling with the cotton-wool plugs in the flasks. After another twenty-four hours repeat the boiling. Now set the flasks away for several days, allowing the cotton wool plug to remain undisturbed in one; removing it from the other.

Examine the flasks daily. Account for the fact that the liquid in the closed flask remains unchanged, while that in the open flask becomes turbid. Notice that a skin forms on the surface of the liquid in the open flask, — the *pellicle* or *zoöglœa* stage of Bacteria. This pellicle begins to form as soon as the conditions become unfavorable for further growth by cell division. It is during this stage that resting spores are principally formed.

Examine under the microscope daily some of the liquid from the open flask, using the high power. There will usually be found at first a short rod form with rounded ends and a constriction at the middle, — *Bacterium termo.* Later the longer rods and Leptothrix filaments of *Bacillus subtilis* will be abundant. Other forms may be present.

3. Let five ounces of Pasteur's fluid with much sugar receive a little yeast and work for a day or two. Kill the yeast by heating above 50° C. Set aside for two or three days and then examine the liquid below the zoöglœa. Spread a little on a cover glass in a thin, even layer, diluting with water if necessary, and let it dry in the air. Then, holding the cover glass, prepared side up, with the forceps, pass it several times back and forth through the hot air just above a gas flame to fix the Bacteria thoroughly

to the cover glass. Be careful not to burn. Float the cover glass, prepared side down, on a solution of gentian violet for ten minutes or longer. Wash by immersing in water, let it dry in air, and pass through the hot air above a flame. Invert the cover glass on a small drop of Canada balsam on a slide. Preserve as a permanent mount.

4. Examine a bit of the pellicle formed on the Pasteur's solution and also some of that on the solution of vegetable matter. Observe that the Bacteria are motionless and that they are imbedded in a transparent, gelatinelike mass.

5. Allow a piece of raw fish or meat to stand in a vessel of water for some days. Examine from time to time for Bacteria. The succession of forms that will appear will afford good material for instructive study. Among other forms, numerous motile spiral forms will be found, — Spirilla and Spirochætæ. Draw some of the larger forms.

6. In a similar way study the Bacteria that will surely be found in any other putrefying substances.

7. After Bacteria have been found in abundance in the Pasteur's solution (see Number 3), place a little of the solution in each of two test tubes. Wrap one of the tubes in thick, opaque paper. Set the two tubes aside for two or three days or more, with all other conditions the same for both. Determine whether light is necessary for the growth of the Bacteria.

References for Reading. — Parker's "Elementary Biology," pp. 82–94; Bidgood's "Elementary Biology," pp. 59–71; Klein's "Micro-Organisms and Disease"; Woodhead's "Bacteria and their Products"; Huxley and Martin's "Practical Biology," pp. 408–414; Vines' "Text-Book of Botany," pp. 280–283; Goebel's "Classification of Plants," pp. 24–27; Sachs' "Physiology of Plants," pp. 384–386; Schenck's "Manual of Bacteriology"; Strasburger and Hillhouse's "Practical Botany," pp. 221–224; the author's "Practical Methods in Microscopy," 2d ed., pp. 171–197; Strasburger, Noll, Schenck, and Schimper's "Lehrbuch der Botanik," pp. 269–272.

IV.

THE ALGÆ.

The **Algæ** are all chlorophyl-bearing plants. A very large number of plants is here included. They are all comparatively simple, but differ among themselves widely in the degree of complexity of structure. They all live in the water, though certain forms can exist in a dried-up, inactive condition for indefinite periods of time; these latter forms multiply and develop only when moisture is present.

In the processes of reproduction there is a considerable range of variation. It is believed that both a sexual and an asexual mode of reproduction occur in nearly all cases; this point is not, however, settled in quite a number of families, owing to the lack of sufficient investigation. The mode of asexual multiplication differs in the different families from the simple fission of the cells to the formation of nonmotile *tetraspores* in one class up to the formation of self-motile zoöspores, which is the prevailing mode.

The possession of chlorophyl is not the principal reason for associating together the plants known as Algæ; it is the general similarity of the course of development of the plants which has determined this point in the classification. Neither is it merely the possession of the green, brown, and red colors which determines the separation of the Algæ into their three principal classes: it is rather because, in each of these classes, the course of development shows distinctive characteristics.

The principal classes are:

CLASS I. THE GREEN ALGÆ (*Chlorophyceæ*).
CLASS II. THE BROWN ALGÆ (*Phæophyceæ*).
CLASS III. THE RED ALGÆ (*Rhodophyceæ* or *Florideæ*).

CLASS I. **The Green Algæ** (*Chlorophyceæ*). — Simplicity in the cell structure of the thallus is a characteristic of the Green Algæ. The position of the cilia at the extreme tip of the zoöspores is a further characteristic. The plants are either single cells, filaments of cells, or superficial cell surfaces, approaching the structure of solid cell aggregates in the Stoneworts. The color is a pure green except in some resting spores and in the reproductive branches of the Stoneworts, which become red, brown, or black by the formation of decomposition products in the chlorophyl.

There is in many cases an alternation of generations from sporophyte to gametophyte. The asexual multiplication is in some cases by the simple fission of cells; in others by the formation of ciliated zoöspores; in some cases no asexual multiplication is known to occur. The sexual multiplication is in some plants by the union of two cells that are apparently just alike. When union takes place between cells of the same form, it is said to be *isogamous*. This union is called conjugation; the cell that results is called a *zygospore*. In other plants the sexual multiplication is by the union of one cell with another of quite different appearance. The male gamete is called an *antherozoid* or *spermatozoid;* the female gamete, an *oösphere*. The cell which results from this union is called an *oöspore*, and the union is said to be *heterogamous* or *oögamous*.

The subdivisions of the Green Algæ are the *Siphoneæ* or *Cœloblastæ*, *Volvocineæ*, *Protococcaceæ*, and *Confervoideæ*. The *Conjugatæ* and *Characeæ* are considered to be forms collateral with the Confervoideæ.

The Siphoneæ or Cœloblastæ. — These are branched filamentous plants, each consisting of one cell, there being no transverse divisions except where the reproductive

FIG. 34. — Vaucheria. Filaments of the plant in the vegetative condition, showing the mode of branching and the lack of partitions.

organs are formed. The protoplasm is continuous throughout the filaments. The plants vary considerably in size, and occur under somewhat different conditions. They are of common occurrence in both fresh and salt water.

The Siphoneæ are well represented by the **Vaucheriaceæ** or **Green Felts.** These are for the most part fresh-water plants, though a few species are found in salt water. They grow in the water and on the bottom and sides of ponds and ditches, and on the wet ground around springs, forming feltlike masses of a dark green color. They are abundant in damp places in greenhouses on the ground, and on the surface of the soil in the beds and in the flower pots. The lack of partitions across the filaments at once distinguishes these plants from the other Green Algæ. The protoplasm does not fill the filaments but, leaving the central portion empty, forms a thin lining next to the cellulose wall. Minute chlorophyl granules, together with numerous little shining drops of oil, are scattered regularly through the protoplasm. Numerous nuclei are present, but they are difficult of demonstration.

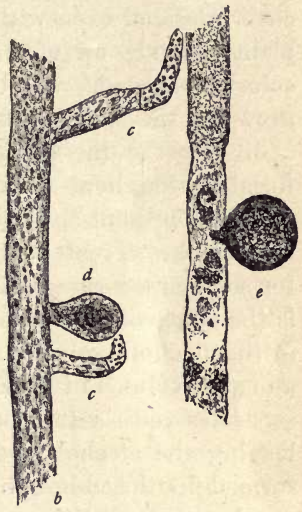


FIG. 35. — Vaucheria. *b*, fruiting filament; *c*, antheridium; *d*, oögonium; *e*, resting spore. Magnified.

No alternation of generations is known to exist in the Siphoneæ. The plant is the gametophyte.

VAUCHERIA. — PRACTICAL STUDIES.

1. Examine with the naked eye and with a hand magnifier a quantity of Vaucheria. Notice its dark green color and feltlike appearance.

2. Mount a little in water and examine with the low power. To secure good mounts care must be exercised,

as the plant is very delicate. Place a mass of the Vaucheria in water and agitate the water until some of the plant filaments separate from the mass, free from adhering dirt. Transfer some of these filaments to a slide with a camel's hair brush. To prevent crushing the plant support the cover glass with pieces of very thin cover glass, or even with bits of paper. Notice that each plant is made up of a single branched cell. Look for colorless rhizoids, which may be found if the specimen grew on the surface of soil. Draw a typical filament.

3. Observe the green chromatophores scattered uniformly throughout the cell. Treat with iodine solution. Is starch present? Iodine solution turns starch blue or blue black. Treat a quantity of Vaucheria with alcohol for some minutes. Note the color of the alcohol. What is the effect on the color of the Vaucheria? To a little of the alcoholic solution of chlorophyl in a test tube add an equal volume of benzol and shake. The benzol, which separates and rises to the top, extracts a blue-green color, leaving the alcohol colored yellow green. The starch is formed in the chlorophyl bodies and is dependent upon the healthy condition of the chlorophyl.

4. Place some Vaucheria in ordinary water and another portion in water that has been boiled to drive out the carbon dioxide. Set both in the sunlight for some hours. Observe whether bubbles of gas rise in equal abundance from both. The gas is oxygen. Chlorophyl-bearing plants decompose carbon dioxide, assimilate the carbon, and set oxygen free. Test some of the Vaucheria from each vessel for starch. Is carbon dioxide necessary for the production of starch? Let both vessels stand two or three days. Is carbon dioxide necessary for the healthy growth of the plant?

5. Place some Vaucheria in each of two vessels of ordinary water. Expose one to direct sunlight and exclude

the light entirely from the other, having all other conditions the same. After two or three days determine whether the sunlight is necessary for the healthy development of the plant.

6. In a fresh mount of Vaucheria look for bright shining oil globules scattered among the chromatophores. Treat with a one per cent solution of osmic acid. This demonstrates the presence of oil globules by turning them black.

7. Run under the cover of a fresh mount ten per cent salt solution and study the *primordial utricle* or layer of protoplasm which lines the cell. The salt solution finds easy entrance through the cellulose cell wall, but does not so easily find entrance to the cell contents. It also extracts water from the cell contents, which consequently assume a diminished volume. This treatment is called *plasmolyzing* the cell.

This experiment is also very instructive as illustrating the manner in which the solutions that furnish nutriment to plants which grow wholly immersed in water find entrance to the cells. As a further illustration, tie pieces of bladder over the ends of a short piece of glass tube, of a diameter of about half an inch, having filled the tube with a saturated solution of sugar in water. Immerse in water, and after a time the bladder diaphragms will be bulged out because water has passed through them into the sugar solution by *endosmosis;* sugar also passes out by exosmosis, as may be determined by tasting the water or submitting it to chemical tests.

8. Run dilute caustic potash under the cover of another preparation and study the cell wall. Treat still another mount with Schultze's solution; this solution stains normal cellulose blue or violet. Is the cell wall composed of normal cellulose?

9. Keep some of the Vaucheria moist and in the dark

for some time previous to the examination. Mount some in water without a cover glass and look for filaments with enlarged ends. If present, find as many different stages of development as possible. This is the asexual mode of reproduction. The ends of the filaments enlarge and become cut off from the rest of the filament by a septum; the protoplasmic contents assume an ovoidal form and become invested with cilia arranged in pairs; the end of the filament opens, and the zoöspore swims out by the action of its cilia. The motion of the zoöspore may continue for only a few minutes, or it may last for some hours. As soon as it comes to rest it loses its cilia, develops a cell wall, and grows into a new plant. The observer who succeeds in finding these zoöspores is rewarded by the sight of one of the most beautiful objects in the plant world. The zoöspores are gonidia.

The observation of the formation of zoöspores in a species of Vaucheria by the botanist Unger in 1826 was the discovery of the fact that certain plants pass through a motile stage in their existence. The discovery of protoplasm and the correction of the older idea that the cell walls possess life was a natural sequence to this discovery. No other discovery has had so much to do with the revolution that botanical science has undergone in the last half century.

10. Find filaments bearing the sexual reproductive organs. In most species of Vaucheria both the male and female organs are borne on the same filament, *i.e.*, the plants are monœcious. These organs originate as lateral branches near together on the same side of the filament. (See Fig. 35, *c* and *d*.)

As the oögonium matures, it assumes a shape that has been described as "like a bird's head"; a septum forms at its base which separates it from the filament, thus forming the ovary; its distal end becomes gelatinized and

breaks away, leaving the naked protoplasm within exposed. This protoplasm is the female gamete; it is somewhat ovoidal in shape, is coarsely granular, and is of a dark green color.

The antheridium is longer and more slender and is curved. It is lighter in color, as there is but little chlorophyl present. The distal end becomes cut off from the rest by a transverse partition ; the protoplasm of this portion breaks up into numerous antherozoids, each having a pair of flagella, — the male gametes.

When fully mature, the antherozoids swim out through the upturned outer end of the antheridium and find their way to the entrance of the oögonium. One, at least, of the antherozoids fertilizes the ovum. A resting spore is thus formed, which assumes a reddish-brown color, becomes encysted in a thick cellulose wall, and develops oil globules in the interior. After its period of rest, the resting spore develops into an ordinary Vaucheria plant, which passes through several generations by the asexual mode of reproduction before resting spores are again formed. Draw a typical pair of the reproductive organs.

References for Reading. — Parker's "Practical Biology," pp. 169–175; Dodge's "Elementary Practical Biology," pp. 267–272; Boyer's "Elementary Biology," pp. 124–127; Bower's "Practical Botany," pp. 429–436; Goebel's "Classification of Plants," pp. 32–34; Strasburger and Hillhouse's "Practical Botany," pp. 250–254; Sachs' "Physiology of Plants," pp. 732–734; Bennett and Murray's "Cryptogamic Botany," pp. 280–282; Carpenter's "The Microscope," pp. 491–493.

The Volvocineæ. — The characteristic that distinguishes these plants is the formation of a *cœnobium*, which is a colony composed of cells that result from repeated fissions of a mother cell. The number of cells that compose the colony is always some multiple of two. These cells are held together in regular form by a sheath of a gelatinous nature. Here are included some forms of singular beauty

and interest. Among the common organisms are the following:

Pandorina is a sphere made up of sixteen minute cells inclosed in a gelatinelike mass. Each cell is provided with a pair of flagella, which project through the gelatinous envelope.

The reproduction of the plant is effected in two ways, asexually and sexually. The asexual reproduction is by the breaking up of each of the sixteen original cells into sixteen still more minute cells. The gelatinous covering then dissolves and sets these sixteen young groups of cells free. Each group becomes invested with an envelope of its own and develops into a full-sized sphere.

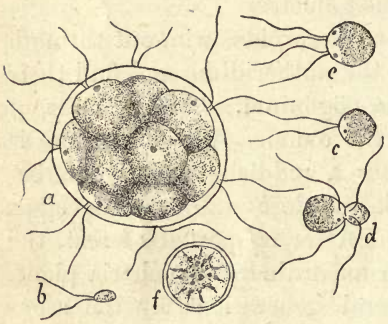


FIG. 36. — *Pandorina morum* Ehrb. *a*, swarming cœnobium inclosed in a gelatinous sheath; *b*, *c*, swarm cells; *d*, *e*, conjugation of gametes; *f*, resting spore. (× 500.) (From Bennett and Murray, after Pringsheim.)

The beginning of the sexual process is similar to the asexual. Each of the original sixteen cells breaks up into sixteen cells, each of which is set free by the breaking away of the gelatinous covering. Each cell is provided with two flagella which enable it to move about. Two of these cells meeting (Fig. 36, *d* and *e*) unite their contents into a spherical mass which becomes invested with a cell wall. The sphere thus formed is the resting spore. (Fig. 36, *f*.) After a time, when the conditions for growth are favorable, the cell wall decays and sets free the two or three little cells that have formed within it. Each of these cells has a pair of flagella. After a period of activity, it comes to rest, and the cell contents divide and sub-

divide to form sixteen cells covered with a gelatinous envelope, thus producing a new plant similar in all respects to the original.

Volvox globator is another quite common organism. It is a gametophyte. This tiny little organism, which has long been an object of peculiar interest to microscopists, is the best known plant of its class. It reaches a size just visible to the naked eye, and is found floating on the water in still pools. A good way to look for it is to place quantities of pond weeds and scums in glass dishes, allow them to stand undisturbed for a time, and then search with a hand magnifier for little green specks rolling through the water. Volvox was long supposed to be an *animal;* later it was regarded as a colony of animals. Professor Stein, an eminent German biologist, describes it as an animal, in a work published in 1878. Biologists now generally class it as a colony of plants, though some prefer not to express a positive opinion. The colony is spherical in shape, the interior being hollow. The shell of the sphere, so to speak, is composed of a great many little green cells. These cells are larger at one end than at the other, and the little end, which has a pair of flagella, protrudes from the surface of the sphere. The colony is motile, the motion being produced by the lashing of the water by the flagella. Under their combined influence the colony rolls or glides

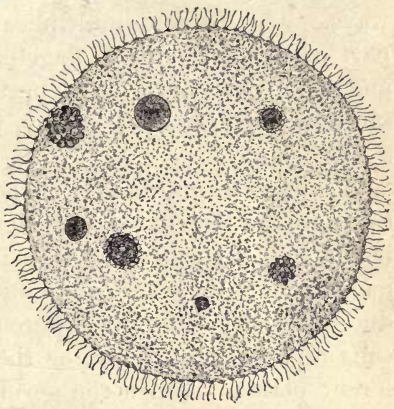


FIG. 37. — *Volvox globator,* showing the formation of daughter colonies in the interior.

along, or simply rotates in its position without motion from place to place.

The whole colony is green in color because of the presence of chlorophyl granules in the protoplasm of the flagellate cells. These cells closely resemble the flagellate cells of *Protococcus pluvialis*, and could hardly be distinguished from them were it not for the manner in which they form spherical aggregations, while the cells of Protococcus naturally separate.

The reproduction is by both the asexual and the sexual ways. The asexual multiplication occurs in the earlier part of the season. A flagellated gonidial cell divides and subdivides into many parts, which escape into the interior of the mother colony, where they unite to form a new colony.

The sexual multiplication occurs late in the season. Some of the flagellated cells develop into sperm cells, the male gametes; others develop into germ cells, the female gametes. Both germ cells and sperm cells may be produced by the different differentiation of the flagellated cells of the same colony, or they may be formed on different plants. When the germ cells have matured, they are loosened from their positions in the shell of the colony and pass into the hollow interior. In the sperm cells a great many antherozoids or minute cells provided with flagella are developed. These are set free by the breaking down of the wall of the cell in which they are formed, and, swimming about, find their way into the interior of the colonies containing the germ cells, which they meet and fertilize. There results a resting spore with a thick cell wall. After a period of rest, the resting spore, when favorable conditions exist, resumes active life. Its protoplasm breaks up into a great many small cells which assume the spherical form and grow to be a full-sized colony.

References for Reading. — Carpenter's "The Microscope," pp. 479–485; Goebel's "Classification of Plants," pp. 34–38; Bennett and Murray's "Cryptogamic Botany," pp. 292–295; Parker's "Elementary Biology," pp. 267–270; Sachs' "Physiology of Plants," pp. 728–730; Vines' "Text-Book of Botany," pp. 237, 238.

The Protococcaceæ. — A large number of primordial plants are included in this class; but, inasmuch as their life histories are only imperfectly known, it is not certain that plants described under different names are not different forms of the same plant. In some plants no alternation of generations from gametophyte to sporophyte is known; in other cases such an alternation is distinct.

Among the most common plants are the different forms of *Protococcus*. The commonest of these is *Protococcus viridis*. *Protococcus pluvialis* is a form containing enough of a red pigment to give a decided red spot to each cell; it is found in stagnant rain water. *Protococcus nivalis*, or red snow, is the interesting plant that sometimes coats the snow with red in a single night in the higher latitudes and on the mountains.

Other common forms are *Chlorococcus*, occurring in small aggregations of cells, each of which is surrounded by a comparatively thick envelope of a gelatinous nature, *Raphidium*, occurring as long, slightly curved cells pointed at each end, either singly or in small groups, with the cells crossing one another at their middle portions; *Scenedesmus*, occurring as crescent-shaped cells, usually in groups of four, not crossing one another. *Tetraspora*, as the name implies, occurs in groups of four cells, which closely resemble the nonmotile cells of Protococcus, but are imbedded in

38

39

FIG. 38. — *Scenedesmus obtusus* Mey. (× 400.) (From Bennett and Murray.)

FIG. 39. — *Raphidium falcatum* Ktz. (× 800.) (From Bennett and Murray.)

an abundant gelatinous substance. This plant shows finely the typical multiplication by cell division. The hyaline envelope holds the cells in position, and besides single cells, two, four, and eight celled colonies are arranged with great regularity. Tetraspora may be found on the bottom and on rocks in clear, swift-running streams.

FIG. 40. — *Tetraspora lubrica.* The transparent gelatinous substance which surrounds the cells and holds them in position is not shown in the figure. (From Gray.)

Pediastrum occurs in colonies made up usually of sixteen cells. These form a flat disk which floats on the water.

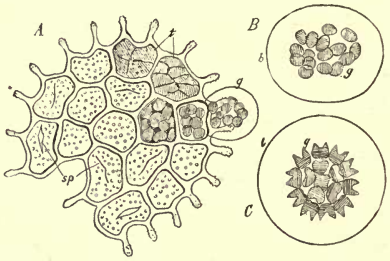


FIG. 41. — *Pediastrum granulatum.* (×400.) *A*, a disk of cells adhering to one another; at *g*, the innermost layer of the wall of a cell is just issuing from the cell, and contains the daughter cells formed by division of the green protoplasm; at *t*, various states of division of the cells; *sp*, slits in the walls of cells which have discharged their contents. *B*, the inner lamella of the wall of the mother cell disengaged from the cell and much enlarged; *b* contains the daughter cells *g*, which are in lively swarming motion. *C*, the same family of cells four hours and a half after its birth; four hours after the small cells have come to rest they have arranged themselves into a disk, which is already beginning to develop into such a one as *A*. (From Goebel, after A. Braun.)

Hydrodictyon, or the **Water Net**, is common in some places. It attains a considerable size, sometimes being six or seven inches in diameter. It is made up of a green open network of filaments or tubular cells.

The asexual reproduction is brought about by the formation of a great number of swarm spores in certain of the tubular cells. If the cell is ob-

served at the right time, these swarm spores may be seen in active motion. The motile condition does not last long, but the spores arrange themselves in a methodical way in the cell. The cell wall now breaks down, and the colony of little cells develops into a full grown Water Net, which escapes through the gelatinous wall of the mother colony.

There is also a sexual method of reproduction. Enormous numbers of *microzoöspores* are formed in certain of the tubular cells of the mother colony. By the breaking down of the cell wall, these microzoöspores escape. Each has a red spot known as the *eye spot.* Each also has four flagella. After a period of motility, they come together in pairs and form green zygospores enveloped with a wall of cellulose. This is the resting spore. It closely resembles the resting spore of Protococcus. Buried in the mud at the bottom of ponds and streams, these resting spores retain their vitality against drought for a long time, but will not endure exposure to strong light. When the conditions are again favorable for growth, the endochrome, or colored contents of the spore, separates into either two or four parts, the cellulose wall breaks away, and the newly formed zoöspores work their way out of the cell by means of the two flagella with which each is provided. They are not very active. They soon become angular in shape, in which condition they rest for a time. They then divide and subdivide, forming numerous microzoöspores, which are active for a time. These then arrange themselves in the net form, develop a new gelatinous covering, and grow very rapidly into a full sized Water Net. The alternation of generations is clearly seen in Hydrodictyon. The plant itself is the gametophyte; the resting zygospores and the angular resting spores represent the sporophyte.

The other plants of this class are not so abundant as

Protococcus, and yet they are frequently found in gatherings from still water.

References for Reading. — Bennett and Murray's "Cryptogamic Botany," pp. 296–298; Carpenter's "The Microscope," pp. 495–498; Goebel's "Classification of Plants," pp. 39–41.

PROTOCOCCUS. — PRACTICAL STUDIES.

Protococcus viridis is abundant on the north side of old unpainted buildings and fences and on trees, forming a very noticeable green incrustation; it is especially distinct in wet weather. It may be obtained for study at any season of the year from these sources. It also frequently occurs during hot weather in abundance in stagnant pools of water.

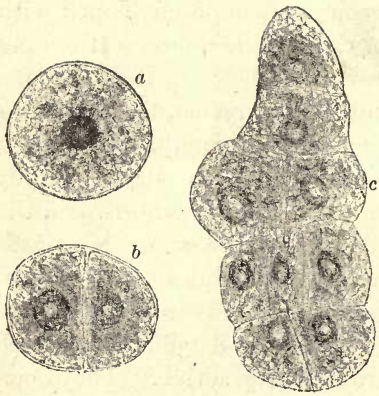


FIG. 42. — Protococcus in the vegetative condition, showing the mode of multiplication by cell division.

1. Place a quantity of Protococcus in alcohol for several hours and observe the yellowish-green color imparted to the alcohol by the chlorophyl. Mount some of the cells so treated and observe that the color has been entirely removed.

2. Mount a little freshly gathered Protococcus in water. Notice that while many cells occur singly, others occur in variously arranged groups. (See Fig. 42.) The positions of the cells in groups show that the organism is reproduced by cell division. Observe a reddish spot or tint in many of the cells. Hæmatococcus, a form of Protococcus found in stagnant rain water, receives its name from the abundance of this red pigment. The chlorophyl

is collected in masses scattered through the cells — the chlorophyl bodies or chromatophores. Draw a single cell and a group of cells, showing the minute structure.

3. Run a little iodine solution under the cover glass; the cell contents take a yellowish-brown color, showing that protoplasm is present. A nucleus containing a nucleolus can be seen in each cell unless the iodine solution is too strong and gives too intense a coloration. The cell wall is unaffected by the iodine. Draw and compare with drawing under Number 2.

4. Run sulphuric acid into the preparation that was stained with iodine in Number 3. The cell wall turns blue or violet. It is, therefore, composed of cellulose such as is found in ordinary plants. Treat a fresh mount with Schultze's solution, which should give the same result.

5. Place pieces of bark bearing Protococcus in a glass of water and expose to the sunlight for several days. Observe that bubbles of gas rise from the water. It is oxygen. Protococcus growing in pools of stagnant water under favorable conditions gives off oxygen so freely that a dense, frothy scum forms on the surface of the water. If some Protococcus from such a pool be placed in a test tube inverted over mercury, the oxygen gas may be collected in such quantity that it may be tested by a spark.

6. Examine scrapings from the bark used in Number 5, or Protococcus from a stagnant pool, under high power. The mount will be found to be swarming with rapidly moving organisms. These are the zoöspores, or motile forms of Protococcus. Large forms, megazoöspores, and small ones, microzoöspores, will be present. It is hard to persuade one's self that they are not animals. (Fig. 43, *B.*) The motion is produced by the rapid lashing of the water by two flagella, which extend from the anterior end of the body of the organism. These can be seen under

high power on motile forms that have come to rest. It is much easier to see them in stained preparations. Run a minute drop of iodine solution under the cover glass and watch its approach to the moving organisms. As the organism dies the flagella come into distinct view. The flagella are believed to be projections of the protoplasm, and their movements are produced by the alternate constrictions of the protoplasm on their opposite sides. Draw a cell showing flagella. The rapid movements of the motile forms, and the fact that some species have contractile vacuoles, — a characteristic of the lowest forms of animals, — have led to doubts as to the classification of Protococcus. Some eminent scientists class it as a plant; others as an animal.

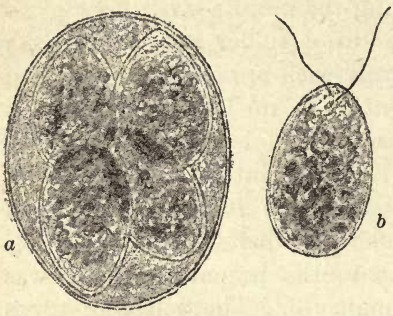


FIG. 43. — Protococcus. *a*, an encysted cell preparing to set free its four megazoöspores; *b*, a megazoöspore or large motile form.

As already noted, the possession of flagella indicates close relationship with the Volvocineæ. It is known that after a time the motile forms come to rest, draw in their flagella, and become invested with a thick cell wall. They are now resting spores.

FIG. 44. — Protococcus. An encysted cell preparing to set free microzoöspores.

6. Find large encysted cells of Protococcus in which the cell contents are broken up into separate parts. The megazoöspores are pro-

duced by the division of the cell contents into four parts (Fig. 43, *a*); the microzoöspores by the division of cell contents into many parts. (Fig. 44.)

References for Reading. — Parker's "Elementary Biology," pp. 23–35; Bidgood's "Elementary Biology," pp. 45–58; Dodge's "Practical Biology," pp. 39–46; Huxley and Martin's "Practical Biology," pp. 389–395; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 22–27; Bower's "Practical Botany," pp. 439, 440; Bennett and Murray's "Cryptogamic Botany," pp. 415–419; Carpenter's "The Microscope," pp. 473–477.

The Confervoideæ. — The plants of this class are either branched or unbranched filaments of cylindrical cells, or

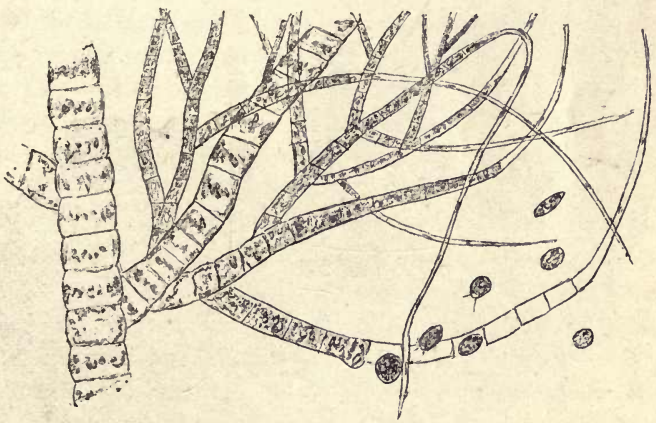


FIG. 45. — Chætophora. The mode of branching is shown; also the formation of motile zoöspores in maturing cells of the branches.

are cell surfaces. The sexual reproduction is in some plants *isogamous*, *i.e.*, it is between elementary cells that cannot be distinguished as male and female. These cells are ciliated and motile; they may develop from any of the cells. The asexual multiplication is by means of ciliated zoöspores, which may also form in any of the cells. These plants grow by the transverse division of an apical cell or

of cells that are intercalated in the filaments. Common plants are *Chætophora* and *Cladophora*. Cladophora, or *Water Flannel*, is very common. It grows in running water, forming long, dark-green stringy masses attached to some fixed support at one end. It is made up of branching filaments, formed of elongated cylindrical cells, with thick stratified walls. The branches develop from a sort of bud formation near the top of the parent cell. As the new branch forms, it becomes separated from the parent cell by a partition wall that forms close to its base. The cells are lined with protoplasm, and are also divided by thin plates of protoplasm into a number of vacuoles.[1]

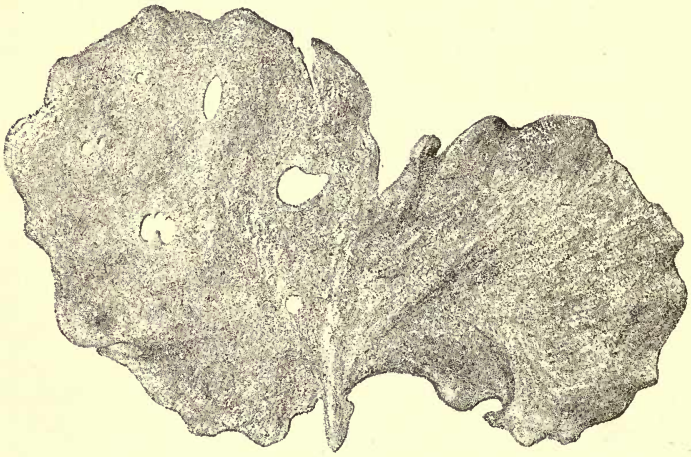


FIG. 46. — Sea Lettuce (*Ulva*).

Another common plant, **Sea Lettuce** (*Ulva*), is recognized by its resemblance to the leaves of garden lettuce; it grows on the rocks and timbers in brackish and salt water.

[1] Chætophora, or Cladophora, affords good material for Practical Studies.

The asexual reproduction is by the successive division and redivision of the cells in particular directions. In outward appearance the plant resembles the higher Flowering Plants, but a more minute examination reveals only the simplest structure of aggregations of cells produced by cell division. There is wanting entirely anything like differentiation of the cells to form tissues of different kinds. The cells are held in position by an investing membrane, but this membrane bears little resemblance to the epidermis of the higher plants. Again, the different parts of the plant differ as little in function as in form, any part being capable of reproducing the plant.

FIG. 47. — Sea Lettuce. The individual cells are shown held together by the investing membrane.

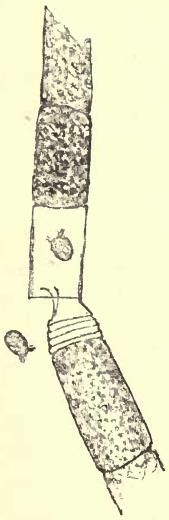
The sexual reproduction begins by the division of the endochrome, or colored contents, of some of the cells into many portions. These portions become motile, the cell wall breaks down, and zoöspores, which are provided with two or four flagella, swim out into the water. The zoöspores are of two sizes. The larger ones, those having four flagella, are called megazoöspores; the smaller ones are microzoöspores. These spores resemble very closely the motile forms of Protococcus.

The megazoöspores cling to some supporting object and develop asexually by cell division into plants; the microzoöspores unite in pairs and form zygospores. The zygospores grow into new plants. The zygospore represents the sporophyte; the ordinary form is the gametophyte; the megaspores are gonidia.[1]

[1] These spores are easily obtained by allowing some of the Sea Lettuce to go to decay in a jar of sea water. Arrange Practical Studies of Sea Lettuce.

Other plants are heterogamous, *i.e.*, the sexual reproduction is by the union of cells distinctly different from each other. Important orders are the *Sphæropleæ*, *Œdogonieæ*, *and Coleochæteæ*.

The **Œdogonieæ** are to be looked for in stagnant and flowing water, either in masses by themselves, or in asso-



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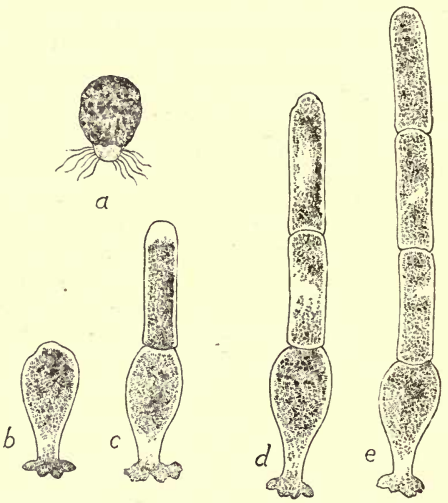

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Fig. 48. — Œdogonium, showing splitting of cells and escape of the ciliated zoöspores.

Fig. 49. — Œdogonium. *a*, zoöspore; *b–e*, young plants. Magnified.

ciation with other plants. They do not usually grow independently, but are supported by other plants, or are attached to stones and the débris that accumulates in still water. The color is green, or brownish-green. The enlarged cells that they bear at intervals distinguish them from other Green Algæ.

The asexual reproduction of Œdogonium presents some points of interest. Large oval zoöspores are formed in

cells that develop near the upper ends of the branches. When ripe, the cells split almost entirely across, the two portions bend apart, and the zoöspore, which has a number of flagella at its smaller and colorless end, swims out. After a period of activity, the zoöspore becomes encysted and attaches itself to some fixed object by its smaller end, which becomes disk-shaped and acts as a sucker. The larger end then grows by the usual process of cell division into a new plant. (See Fig. 49.)

The zoöspores of some species develop in another way. These zoöspores, which are smaller than the common ones, affix themselves by their disk-shaped ends to filaments bearing oögonia. Here they develop into filaments of a few cells, the end cell becoming an antheridium, which liberates antherozoids to fertilize the eggs in the oögonia.

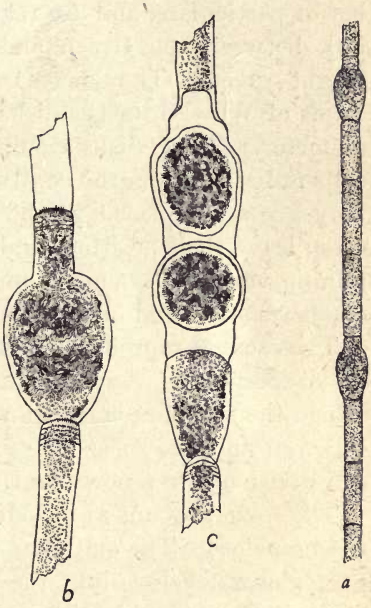

FIG. 50. — Œdogonium. *a*, filament; *b*, showing oögonium; *c*, showing oögonium and resting spore. Magnified.

In the sexual reproduction the oögonia develop as enlarged cells at intervals on the filament. The antheridia develop in other cells on the same or on another filament. Flagellated antherozoids, set free from the antheridia, find their way to the ripened egg cells, developed in the oögonia, and fertilize them. The oöspore thus formed develops a thick reddish-brown wall and becomes a resting spore, which ultimately develops into a

new plant. The oöspore is the sporophyte; the plant itself is the gametophyte.[1]

References for Reading. — Goebel's "Classification of Plants," pp. 44–46; Bennett and Murray's "Cryptogamic Botany," pp. 222–225, Vines' "Text-Book of Botany," pp. 248, 249; Carpenter's "The Microscope," p. 502.

The Coleochæteæ resemble the Red Seaweeds in a number of particulars, and are regarded by some as forming a link between the Green and Red Algæ. The color is bright green. They may be found on the leaves and stems of Water Lilies as disks one or two millimeters in diameter. These disks are made up of branching rows of cells radiating from the central part. If plants on which they grow are placed in the light in glass vessels, they often leave their positions and seek the sides of the containing vessel. Examined under the microscope, numerous hairs are found on the upper surface.

The asexual reproduction is by the formation of flagellated zoöspores. Any of the cells may produce these. When the zoöspore is ripe, a round opening forms in the cell wall and the zoöspore escapes. It then develops by cell division into a new plant.

The sexual organs are produced in the terminal cells of the branches. The end cells elongate, and the contained protoplasm develops into the female reproductive organ, or carpogonium, which is a specialized form of oögonium. The antherozoids are produced in elongations from neighboring cells. (See Fig. 51, *og* and *an.*) The fertilization of the carpogonium by the antherozoid has never been observed, but there is no doubt that it occurs. A covering or *pericarp* now grows from the cells just below the fer-

[1] Œdogonium is very common and is unusually good material for a series of Practical Studies. Have on hand fresh gatherings; also some that is going to decay in a vessel of water. In this way the different forms are almost sure to be found.

tilized carpogonium and envelops it. The pericarp and carpogonium together constitute a spore fruit. This spore fruit preserves the life of the plant until the following season. Then, under favorable conditions, a number of flagellated zoöspores are formed and liberated, which, after

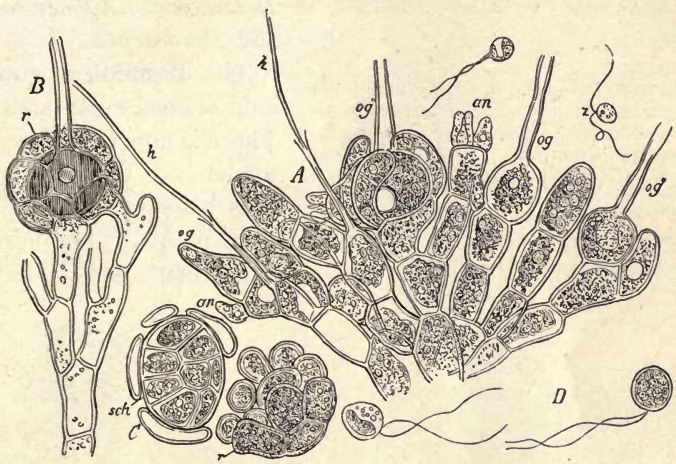

FIG. 51. — *A*, part of a fertile thallus of *Coleochæte pulvinata*, showing the antheridia, *an*, and the oögonia or carpogonia, *og*, in the process of formation. (× 350.) *B*, ripe oögonium in its rind. *C*, germinating fructifications of *C. pulvinata*, in the cells of which the swarm spores are formed. *D*, swarm spores. (*B–D* × 280.) (From Goebel, after Pringsheim.)

a period of activity, develop by the asexual process into new plants. The spore fruit is the sporophyte; the plant itself is the gametophyte.

References for Reading. — Goebel's "Classification of Plants," pp. 46–48; Bennett and Murray's "Cryptogamic Botany," pp. 220–222; Vines' "Text-Book of Botany," pp. 249, 250; Bower's "Practical Botany," pp. 419, 420.

The Conjugatæ. — The sexual reproduction in this class is by the formation of zygospores by the conjugation of cells that are apparently just alike, *i.e.*, it is isogamous. The asexual reproduction is by the transverse fission of

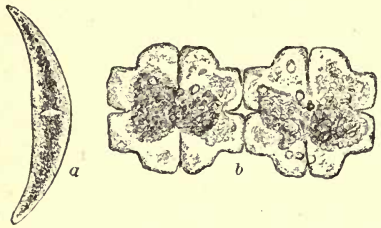

FIG. 52. — Desmids. *a*, *Closterium lunula* in the incipient stage of transverse division; *b*, *Euastrum didelta*. Two cells, still adherent, which have resulted from the division of a single cell. Magnified.

the cells. There is no alternation of generations. The plant is the gametophyte. The three subdivisions are the *Desmidieæ*, *Zygnemeæ*, and *Mesocarpeæ*.

The **Desmidieæ** were long classed as animals. There is now considered to be no doubt that they belong to the plant world. The Desmids are fresh-water plants. They are microscopic in size and are of a vivid green color. They

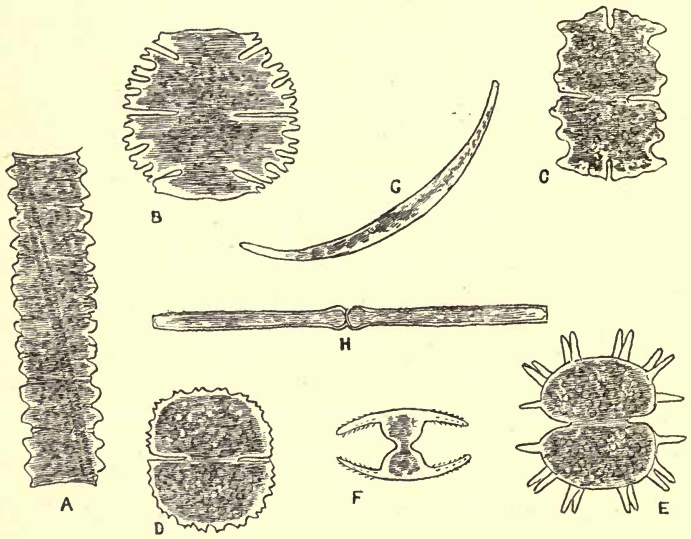

FIG. 53. — *A*, *Desmidium Swartzii* Ralfs; *B*, *Micrasterias rotata* Grev.; *C*, *Euastrum rostratum* Ralfs; *D*, *Cosmarium cælatum* Ralfs; *E*, *Xanthidium cristatum* Bréb.; *F*, *Staurastrum Arachne* Ralfs; *G*, *Closterium Dianæ* Ehrb.; *H*, *Docidium baculum* Bréb. (All from Bennett and Murray, after Ralfs, and variously magnified.)

usually occur isolated, although they are sometimes seen in short filaments, for they grow by the binary division of the cells, and, as in the case of Protococcus and other one celled plants, the cells sometimes remain adherent for a time. The cells are bilaterally symmetrical, *i.e.*, the two halves of each cell are just alike. This fact helps to distinguish some forms from Diatoms. Another distinguishing characteristic is the possession of projecting points

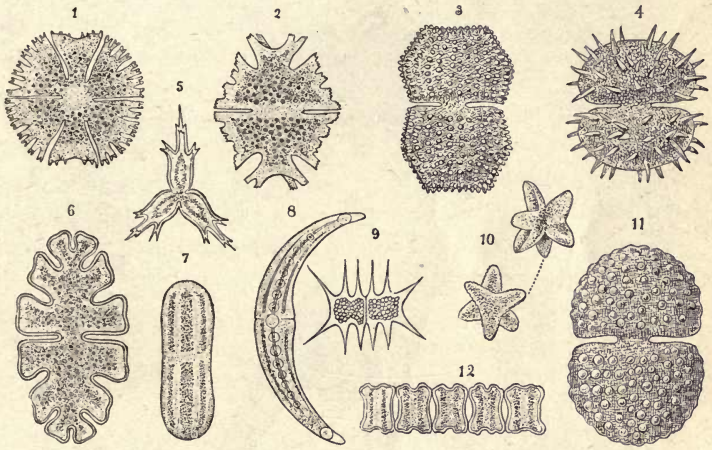

FIG. 54. — Desmids. 1, *Micrasterias papillifera;* 2, *Micrasterias morsa;* 3, *Cosmarium polygonum;* 4, *Xanthidium aculeatum;* 5, *Staurastrum furcatum;* 6, *Euastrum oblongum;* 7, *Penium Brebissonii;* 8, *Closterium lunula;* 9, *Xanthidium octocorne;* 10, two views of *Staurastrum alternans:* 11, *Cosmarium tetraophthalmum;* 12, *Aptegonum desmidium.* The figures are all highly magnified. (Kerner and Oliver.)

or spines. These two facts and the bright green color are great helps in their identification.

The cell contents are inclosed in a cellulose wall of considerable firmness, and a more or less distinct gelatinous covering envelops the cell wall. The protoplasm contains chlorophyl and its product starch, and is arranged in bilaterally symmetrical patterns in the two halves of the

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cell, making the Desmids very attractive objects. The ability which they possess to move about adds to the fascination of their study under the microscope.

A great many varieties of Desmids are found. They are to be looked for associated with plants growing in the water and in the mud on the bottom of slow-flowing

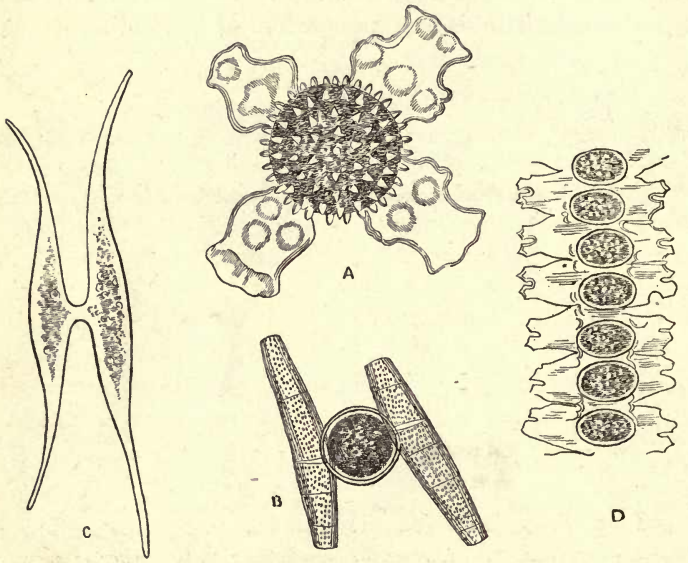


FIG. 55. — Zygospores of Desmids. *A*, *Euastrum pectinatum* Bréb., showing the zygospore and the empty cell envelopes of the cells that united. (× 400.) *B*, *Penium margaritaceum* Bréb. (× 300.) *C*, *Closterium rostratum* Ehrb., early stage, showing two cells just throwing out the connecting tube through which the contents of the cells will pass to unite. (× 200.) *D*, *Desmidium Swartzii* Ralfs. (× 600.) (All from Bennett and Murray, after Ralfs.)

streams, and in the shallow pools of somewhat clear water in swamps and by the roadsides in spring and early summer. Water that is decidedly stagnant or that which flows rapidly will not yield many forms.

The Desmids multiply asexually by the formation of a partition that separates the two halves of an individual

cell. (See Fig. 52, *a*.) Each of these halves develops until it is again bilaterally symmetrical, when the process of cell division may be again repeated.

The Desmids are also reproduced in the sexual way by the conjugation of two individual cells. (See Fig. 55.) The zygospore thus formed grows by the process of cell division. The conjugation seems to take place to give new strength and vigor to the plant.

References for Reading. — Carpenter's "The Microscope," pp. 509–516; Bennett and Murray's "Cryptogamic Botany," pp. 268–272; Goebel's "Classification of Plants," pp. 50–52.

The **Zygnemeæ** are very common and familiar objects, some of them forming great masses upon the surface of stagnant pools and ditches. They are commonly known as *pond scums*. When in active growth the masses are of a vivid though somewhat yellowish green. The plants are unicellular, but as the cells are joined together by a gelatinous covering, they form long unbranched filaments, or linear aggregates. The gelatinous covering gives them a slippery feeling when a mass is taken in the hand.

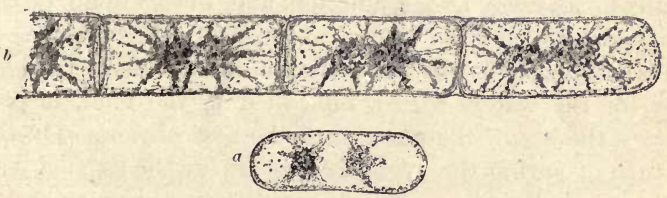


FIG. 56. — Zygnema. *a*, a single cell; *b*, part of a filament which has resulted from repeated transverse divisions of cells. Magnified.

There is a large number of species which are distinguished by the different arrangements of the chlorophyl granules and bands. The disgusting masses of slimy material are resolved into forms of great beauty when seen under the microscope. In some species the chlorophyl

bodies are scattered quite regularly over the entire surface of the cell. In others they collect into two somewhat starlike masses connected by a narrow band, giving a shape resembling a dumb-bell. In others they collect into spiral bands. The last forms are known as *Spirogyra*, of which there are many varieties.

The asexual reproduction is by the transverse fission of the cells. It is the usual process of the division of the protoplasm and the formation of a cellulose wall across the cell. The division takes place in the dark. It is best observed by keeping the plants in a totally dark place for some hours and then examining at once. This mode of reproduction accounts for the long unbranched filaments.

The sexual reproduction may be seen at various seasons, but is more likely to be met with in spring or in summer. When the plant is at this stage, it takes on a brownish color. The male and female filaments cannot be distinguished from each other, even under the microscope, but when two filaments of opposite sexes happen to be in proximity to each other, projections develop on the adjacent cell walls until they meet. (Fig 57, *B.*) The cell walls break away at the junction, and the contents of the male cell are emptied into the other cell. A zygospore is thus produced that becomes encysted and falls to the bottom of the water, where, imbedded in the mud, it preserves the life of the plant until the next season. On the return of spring the zygospore grows in the asexual way into a new filament. This is gonidial reproduction.

SPIROGYRA. — PRACTICAL STUDIES.

1. Observe the light green color of the plant when seen in mass. Notice that most species are slippery to the touch. Place a little in water on a glass slip, hold the slip over a white surface, and notice that the plants form fine un-

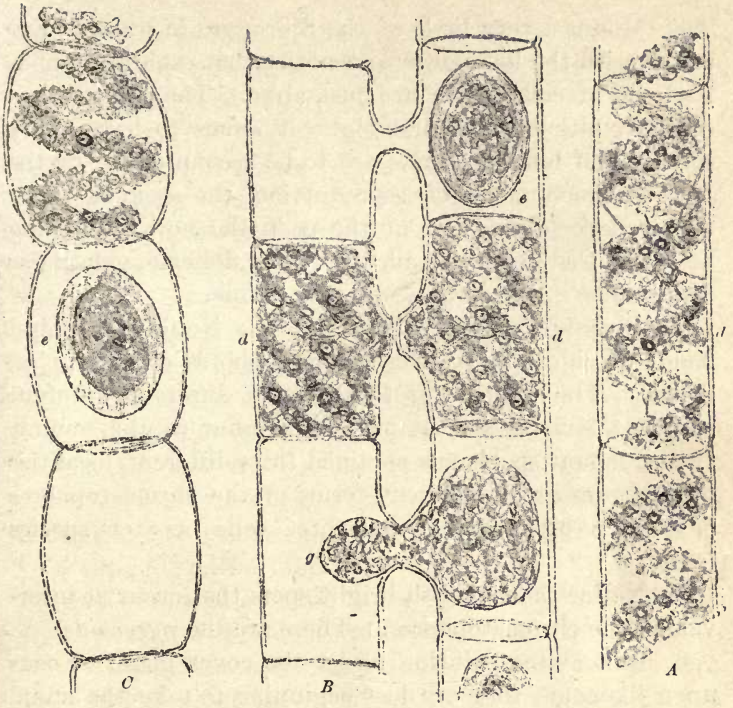


FIG. 57.—Spirogyra. *A*, one whole cell and parts of two others, showing the spiral chromatophore and, at *d*, a nucleus with distinct nucleolus suspended in the center of the cell by bands of protoplasm. *B*, two filaments of a different species of Spirogyra, showing three stages in the process of conjugation; the cells *dd* are just preparing to connect by means of a tube which forms itself from the projecting cell walls; the cell *g* has given up the greater part of its contents to the cell opposite; at *e* a zygospore has formed from the contents of the two opposite cells. *C* shows still a different kind of chromatophore, and at *e* the formation of a zygospore by parthenogenesis.

branched filaments of uniform diameter; use a hand magnifier if necessary.

2. Let a quantity of Spirogyra stand in alcohol for a short time. Then notice the color of the alcohol both by reflected and by transmitted light. Describe the colors. Notice also that the immersed filaments of the Spirogyra are now colorless.

3. Mount a very little of the Spirogyra in water. Examine with the low power and notice that each filament is made up of cells which are just alike. The plant is unicellular, although at first sight it seems to have many cells. The long filaments are to be accounted for by the fact that one mode of reproduction, the asexual, is by the transverse division of the cells, the new cells being held together, end to end, by a very delicate, gelatinous membrane. Any of the cells may divide.

4. Examine with the high power. Notice the spiral bands of chlorophyl — the chromatophores or chlorophyl bodies. The number of these bands differs in different species. Several species may be present in the mount. If not, mount specimens obtained from different localities until a number of different forms of the chromatophores have been observed. Draw three cells of each species found.

5. Notice the roundish bright spots that occur at intervals in the chromatophores. These are the *pyrenoids.*

6. Run iodine solution under the cover glass. Focus upon filaments that are just beginning to take the stain. If the Spirogyra has been in the sunlight for some time, a ring of dark blue, almost black, particles will be seen around each pyrenoid. These are *starch* granules. Keep some Spirogyra in the dark for several hours. Test for starch. Do you find it?

The chromatophores of chlorophyl-bearing plants are the laboratories in which the starch is manufactured. Keep some Spirogyra for one or two hours in water that has been boiled to expel the carbon dioxide. Test for starch. Do you find it? If so, is it as abundant as in Spirogyra kept in water from which the carbon dioxide has not been removed? What conclusion do you draw as to the necessity of carbon dioxide in the formation of starch? Keep Spirogyra in ordinary water in the sun-

light; notice bubbles of gas given off by the plant. This gas is oxygen set free in the chemical changes that occur in the formation of the starch.

In a vessel containing healthy Spirogyra growing in Sachs' solution in the sunlight, arrange a test tube to collect the gas given off. The tube is filled with the solution and supported bottom up with its mouth just below the surface of the solution. Let the stem of an inverted funnel rise into the tube, the flaring portion of the funnel being in position to catch the bubbles of gas. Let the apparatus stand until a quantity of the gas has collected, agitating the Spirogyra below the mouth of the funnel from time to time to dislodge the bubbles which cling to the plant. Test the gas by introducing a spark on the end of a splinter of wood. The spark glows more brightly, or kindles into a flame, showing that the gas is oxygen.

7. Run glycerine under the cover glass of a specimen that has been treated with iodine solution. Note that the slightly stained protoplasm shrinks from the cell wall. The cells may also be plasmolyzed by running ten per cent salt solution under the cover. The protoplasm contracts and the primordial utricle is brought into view. Notice the large centrally situated vacuole.

A short piece of glass tubing closed at both ends and covered with paper gives a good idea of the Spirogyra cell. The paper represents the transparent cell wall; the glass represents the thin lining of protoplasm or primordial utricle; the hollow interior, which in the Spirogyra is, of course, filled with cell sap, represents the vacuole. The nucleus is suspended in the center of the vacuole.

8. Run solution of caustic potash under the cover glass. This brings the cell wall into more prominent view. Trace a filament to its end. Notice that the filament is of uniform width, with perhaps an occasional accidental enlargement or contraction, the cells being of the same shape with

the exception of the end cell, which differs from the others only in having its extremity more rounded.

9. Run Schultze's solution under the cover glass of a fresh mount. Notice and describe the effect on the cell wall and on the cell contents.

10. Find the nucleus in a fresh mount. In some species the nucleus is very prominent; in others it can be made out only after special treatment. In difficult cases leave some Spirogyra in a one per cent solution of picric acid for several hours, wash out the acid in water, followed with 35 per cent alcohol, stain in Grenacher's borax carmine, wash again in 35 per cent alcohol, and mount in 66 per cent glycerine.

By searching material from different localities, good specimens are usually found which show the nucleus without this special treatment. Draw a cell, showing all the details of structure, especially the nucleus, nucleolus, and the manner in which they are suspended in the center of the cell by strings of protoplasm running to the pyrenoids. (Compare Fig. 57, *A* and *B*.) Treat different mounts of material showing the nucleus with iodine, alcohol, ten per cent salt solution, and with different stains.

11. Find material in the conjugating condition. Here again it may be necessary to search the material from several localities. Find, if possible, specimens in which the zygospores are formed in the cells of one of the filaments, and others in which they are formed in the conjugating tubes between the filaments. Draw in detail typical cases.

12. Try to find material in which the contents of the cells of a filament have become aggregated into spores without conjugating with the cells of another filament. Such cases may be recognized by the fact that the cell walls are still entire and show no indications of having given out conjugating tubes, or of having received such

tubes from another filament. (See Fig. 57, *C*, *e*.) These spores are produced by parthenogenesis.

13. Place some freshly gathered vigorous Spirogyra in a refrigerator over night. In the early morning examine for the division of the cells by the asexual process. This division takes place, under natural conditions, at about the middle of the night. Cold delays the process. Make drawings showing as many different stages as are found.

References for Reading. — Parker's "Elementary Biology," pp. 149–200; Goebel's "Classification of Plants," pp. 48–50; Bennett and Murray's "Cryptogamic Botany," pp. 264–266; Vines' "Text-Book of Botany," pp. 244–246; Sachs' "Physiology of Plants," pp. 727, 728; Huxley and Martin's "Practical Biology," pp. 396–407; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 33–42; Bessey's "Essentials of Botany," pp. 122, 123; Campbell's "Structural and Systematic Botany," pp. 30–33; Dodge's "Practical Biology," pp. 51–61; Boyer's "Elementary Biology," pp. 121–124; Strasburger and Hillhouse's "Practical Botany," pp. 207–209, 246, 247; Bower's "Practical Botany," pp. 442–446.

The **Mesocarpeæ** are distinguished from the Zygnemeæ by the arrangement of the chlorophyl in straight bands in the longitudinal direction of the cell rather than in spiral coils and dumb-bell-shaped figures. The sexual multiplication is by a process of conjugation similar to that of the Zygnemeæ; the asexual reproduction is by the separation and subsequent fission of the cells of the filaments.

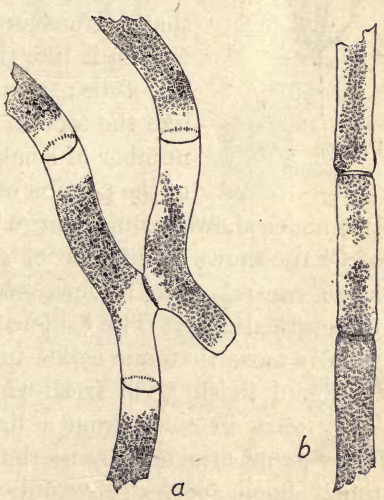


FIG. 58. — Mesocarpus. *a*, conjugating cells; *b*, vegetative cells.

References for Reading. — Bennett and Murray's "Cryptogamic Botany," pp. 260–263; Vines' "Text-Book of Botany," p. 246; Goebel's "Classification of Plants," p. 49; Carpenter's "The Microscope," p. 478; Campbell's "Structural and Systematic Botany," p. 33.

The Characeæ or Stoneworts. — The Characeæ differ so much from all the plants below them and from all those above them that it is difficult to determine their position. Their place is far from settled, and writers of the highest authority differ in opinion in regard to them. They rank decidedly higher in complexity of structure than any of the plants thus far considered. A large number of species is found in the various parts of the world. Some occur in almost every locality. The species are all comprised in two genera, Chara and Nitella, which may in general be distinguished by the fact that a transverse section of the stem of Nitella is like the section of a single hollow tube; a similar section of Chara is like the section of a tube surrounded by a number of smaller tubes. A surface view of the portion of a stem of Nitella between two nodes shows a single large cell; a similar surface view of Chara shows a number of cortical cells overlying the large central cell. A few species of Chara do not have the cortical cells. The leaflets are single celled in Chara; usually more than one celled in Nitella. The plants may be found in sluggish fresh-water streams and in ponds. They vary in color from a light to a very dark green. They grow attached by rootlets to the mud on the bottom. Some species grow only partly submerged; others are wholly covered by the water. The latter may be looked for by raking the bottom of ponds in the shallow

FIG. 59. — *Chara fragilis.*

water near the bank. The plant stem may be only a few inches in length, or it may reach a length of some feet.

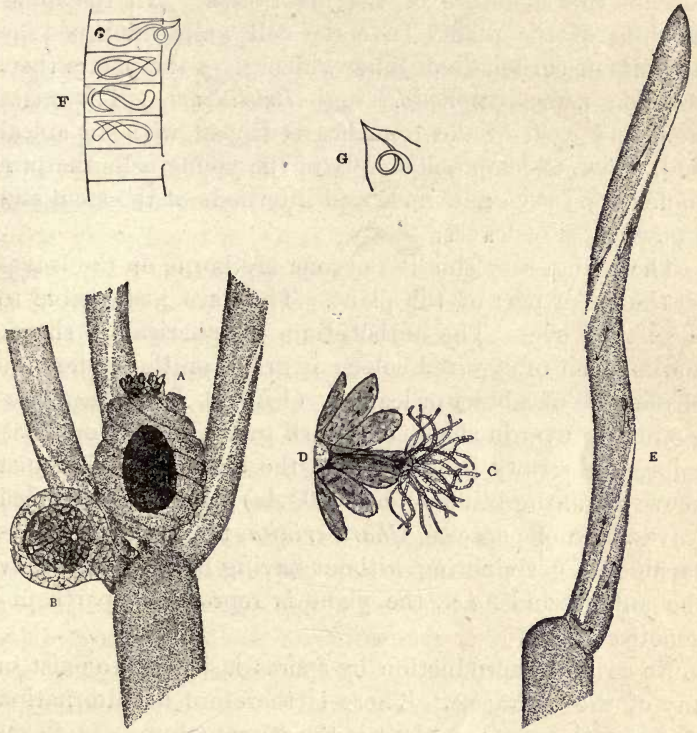


FIG. 60. — *Chara fragilis*. *E* is a single leaf, consisting of one cell and showing the neutral line; the arrows show the movement of the protoplasm in cyclosis. *B* is a ripening antheridium. *A* is an archegonium showing the mature egg cell surrounded by spiral cells and surmounted by a crown of cells. *D* is a manubrium with its surrounding cells. At *C* are represented the filaments of cells in which the antherozoids are produced. *F* and *G* show the ciliated antherozoids after they have been set free. The cortical cells on the stem are not shown in the figure. All are highly magnified.

The diameter is seldom much greater than two or three millimeters.

The leaves grow in whorls from points on the stem called *nodes*. The lengths of stem between the nodes

are called *internodes*. The stem also sends out branches from the axils of the leaves at the nodes, and each branch repeats the structure of the main stem. All the older portions of the plants have the cell walls thickened by deposits of carbonate of lime, which gives the plants their common names, *Stonewort* and *Brittlewort*. The main stem and each of the branches is tipped with an apical bud, which is composed simply of the young cells that are to develop into a new node and internode of the stem and a new whorl of leaves.

The sexual reproductive organs are borne on the leaves on the upper part of the plant. They are just visible to the naked eye. The antheridium is spherical in shape, and is of an orange-red color; it grows on the under side of the base of a bract or leaflet. (Fig. 60, *B*.) The archegonium is oval in shape, of a dark green, brown, or black color, and grows in the axil of the bract or leaflet, just above an antheridium. (Fig. 60, *A*.) Both are modified leaves. In one species, *Chara crinita*, the archegonium is capable of germinating without having been fertilized by the antherozoids, *i.e.*, the plant is reproduced parthenogenetically.

No asexual reproduction by spores is known to exist in any of the Characeæ. There is therefore no alternation of generations. The plant is the gametophyte. A vegetive reproduction by means of branches which fall off from the mother plant and grow into new plants occurs.

THE CHARACEÆ. — PRACTICAL STUDIES.

1. Detach an entire plant of Chara or Nitella from the tangled mass in which it grows. Place it in a shallow dish of water. Examine with a magnifying glass. Find the rhizoids or rootlets. Do you find them at more than one node? Do you find them on the internodes? Are they

of the same color as the stem? Count the leaves in each whorl. Is the number the same? State what number you find. Measure the lengths of the internodes. Are they all of the same length? Describe the reproductive organs as they appear under the hand magnifier. Also the apical buds. Draw the entire plant on as large a scale as your notebook allows.

2. Obtain, if possible, plants of both Chara and Nitella. Examine under the low power. Draw and label an internode of each. Cut cross sections of both, holding the specimen between two pieces of pith. Draw and label a cross section of each. Examine any of the internodes of a Nitella plant or one of the youngest leaves of Chara. Are the chlorophyl bodies arranged in any definite way? Notice the neutral zone that contains no chlorophyl bodies. In what direction does it extend? (See Fig. 60, *E.*)

3. Under both low and high powers examine any of the cells of Nitella or the youngest leaves of Chara for *cyclosis* or rotation of the protoplasm. Handling the specimen often causes the cyclosis to stop. In that case, place plenty of water under the cover glass and put the slide in a warm place for fifteen or twenty minutes, and the cyclosis will again start. Focus into the cell below the chlorophyl bodies. Draw a cell, showing the neutral line, and indicate the direction of the currents by arrows. From time to time the currents stop and after an interval begin in the opposite direction. The cells of Nitella show cyclosis better than any other known plants.

4. Keep some Chara or Nitella in alcohol until the chlorophyl has been removed. Mount in alcohol and run iodine under the cover glass. Is starch present? In another mount of fresh or alcoholic material determine whether the cell walls are composed of normal or fungous cellulose.

5. Examine fresh young terminal leaves of Chara or

Nitella in water. Find chlorophyl bodies that are undergoing division; they are recognized by constrictions at the middle of the cells. Draw.

6. Cut off the end of a young internodal cell and press the protoplasmic contents out into a drop of water on a glass slip. Examine with high power. Describe the changes that occur as the cell contents mix with the water. Do you recognize starch granules? Use iodine solution if necessary. Notice also numerous large and small masses of proteinaceous matter floating in the colorless protoplasm. Do not confound these with the chlorophyl bodies.

7. Dissect a terminal bud with needles and mount in water. Run iodine solution under the cover glass. Find the apical cell. Has it more than one nucleus? Observe the cells below the apical cell and see, if you can, how the nodes, internodes, and leaves result from the division and subdivisions of the apical cell. Draw. The apical cells of Chara and Nitella have been favorite objects for the study of the division of the cell on account of the large nuclei and the clearness of the successive steps in their differentiation. The plant increases in length by the division of these apical cells. In this respect there is a decided advance over plants in which any of the cells may divide.

Place a healthy plant in water in the sunlight. Notice the number and measure the lengths of the internodes. After some days notice if there has been any increase in the number of internodes and in their lengths.

8. Study the antheridium. It may be recognized by the naked eye or a magnifying glass as an orange-colored sphere. (Fig. 60, *B*.) The color is due to a pigment which results from the ripening of the chlorophyl bodies that line the inner surface of the cells. Notice under high power several circular cells on the surface. There are eight of

these on each antheridium. Each of these circles is the outer end of a cylindrical cell which extends inward towards the center. These eight cylindrical cells are the *manubria* or handles. Draw an antheridium, taking pains to represent clearly the circular cells and the polygonal cells which surround them.

By pressure on the cover glass crush an antheridium. Find a manubrium. (Fig. 60, *D.*) On its inner end notice an irregularly spherical cell, the *capitulum;* smaller spherical cells, the *secondary capitula*, project inward from the capitulum, and from each of these grow long filaments composed of minute cells. (Fig. 60, *C.*) Each of these cells produces an antherozoid (Fig 60, *F*), a motile cell which bears two long flagella at its anterior pointed end. Each antheridium bears between 20,000 and 40,000 of these antherozoids. If the antheridium is of the right degree of maturity, the antherozoids can be seen in the cells of the filaments, or swimming about free in the water. Find them if possible. Stain with iodine after they are found, to bring their very delicate transparent flagella into view. Under the cover of another mount run a very little gentian violet and look for the antherozoids in the cells of the filaments. This treatment will also frequently show the divided nuclei in cells near the ends of the filaments that are undergoing division. Draw all that you have seen.

9. Study the archegonium. This also may be recognized by the naked eye or magnifying glass as an ovoid brown, green, or black body situated in the axils of the leaflets or bracts. (Fig. 60, *A.*) Find archegonia in different stages of development. Under high power notice the spiral cells that envelop the egg cell. Focus below the spiral cells on a young archegonium and make out all you can of the egg cell. Notice the crown of cells at the apex of the archegonium. If possible, examine the crown

in both Chara and Nitella and state how many cells compose it in each. When the egg cells are ready for fertilization, antherozoids, which have been set free in the water by the ripening of the antheridium, swim to the crown, find passage down through a central opening between its cells, enter, and fertilize the egg. The egg now matures, protected by its covering of cells. In time the archegonium drops off from the mother plant, sinks to the bottom *in situ*, or is carried by currents to other localities. When the conditions are again favorable, it germinates and produces a new plant. Draw an archegonium.

References for Reading. — Bidgood's "Elementary Biology," pp. 85–111; Parker's "Elementary Biology," pp. 206–220; Bennett and Murray's "Cryptogamic Botany," pp. 173–183; Goebel's "Classification of Plants," pp. 52–64; Carpenter's "The Microscope," pp. 505–509; Sachs' "Physiology of Plants," pp. 95, 96, 453, 454; Strasburger and Hillhouse's "Practical Botany," pp. 37, 202 f, 254 g; Vines' "Text-Book of Botany," pp. 251–255: Huxley and Martin's "Practical Biology," pp. 430–442; Dodge's "Practical Biology," pp. 273–284; Boyer's "Elementary Biology," pp. 128–133; Campbell's "Structural and Systematic Botany," pp. 37–40; Bessey's "Essentials of Botany," pp. 180–182; Bower's "Practical Botany," pp. 409–418.

CLASS II. **The Brown Algæ** (*Phœophyceæ*). — A decided advance in the tissues of the plant thallus and the position of the cilia on the sides of the base of the pointed end of the zoöspores, are characteristics which distinguish the Brown Algæ from the Green Algæ. Chlorophyl is present, but is rendered invisible by the presence of a brown coloring matter, *phycophœin*, which is probably a differentiation product from the chlorophyl. The fertilization is isogamous in the lowest plants; in the higher forms it is oögamous. In many of the plants of this group, however, the process of the sexual fertilization is still unknown. There are two subdivisions based on the character of the swarm spores, the *Phœosporeæ* and the

Fucaceæ. In the former the swarm spores are of the same size and form, though it is believed that some are asexual propagative cells and others are sexual cells or gametes, which conjugate. In the Fucaceæ the male elements are minute antherozoids, each provided with a pair of cilia; the female elements are comparatively large oöspheres not provided with cilia.

In some cases there is a distinct alternation of generations; in others there is none or it is doubtful.

The Phæosporeæ. — The *Kelp* and *Laminaria* of the seashore are well-known plants, many of them showing a considerable degree of differentiation. The differentiation of structure is shown in the stemlike stalk and in rootlike appendages that enable it to cling to some fixed support. In the Pacific and South Atlantic oceans, a giant kelp is found, of 800 or 900 feet in length.

Zoöspores provided with two flagella each are known to be formed in some of the cells, but the union of the zoöspores to form zygospores from which new plants can develop has been observed in only a few cases.

The Fucaceæ or Rockweeds. — These plants are all inhabitants of the salt water. The ordinary Rockweeds are types. They grow attached to the rocks by a disklike expansion of the root ends, so to speak. The stem divides and develops into expanded portions which resemble leaves, being flat, and possessing an enlargement like a midrib. The plants have at intervals air sacs, which are evidently nature's provision for buoying them up.

The only approach to asexual reproduction in Rockweeds is the formation of little shoots on the edges of the larger branches. It is possible that these separate from the parent plant and grow into new plants; this, however, is not established, and asexual reproduction is not positively known to occur. The alternation of generations is therefore unknown.

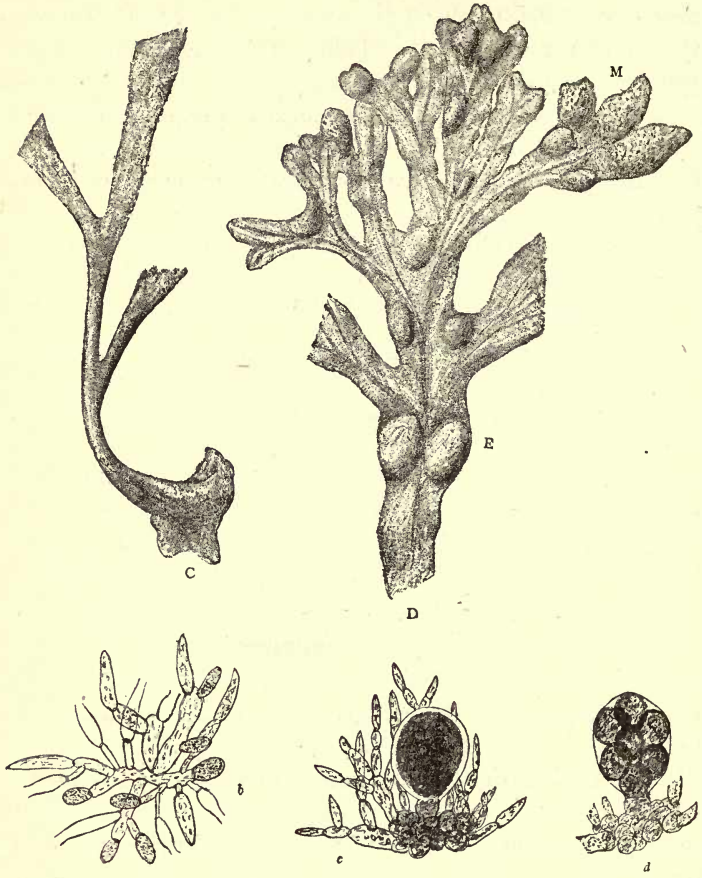


FIG. 61. — *Fucus vesiculosus.* An entire frond is represented, the lower part at *C*, the upper part at *D*. At *C* is seen the disk by which the plant was attached to a rock or other support. At *M* are seen the enlarged ends of branches bearing the conceptacles in which the reproductive cells are produced. At *b*, antheridia with paraphyses are represented; at *c*, an oögonium with paraphyses; at *d*, a ripened oögonium with egg cells ready to burst forth.

The sexual reproduction is better understood. Certain branches become swollen at the ends. In these enlargements the sexual organs develop. The antheridia may be

seen in sections through these enlargements as orange-yellow masses; the oögonia are borne either in the same cavities or in cavities on other plants. The eggs that develop in the oögonia are set free into the water, and the flagellated antherozoids, liberated from the antheridia, find and fertilize them. This, at least, is the belief; but the actual entrance of the zoöspore into the egg has never been observed. After fertilization, the egg secretes a wall about itself, enlarges, attaches itself to some fixed support, and grows into a fully developed plant.

FUCUS VESICULOSUS. — PRACTICAL STUDIES.

Fucus vesiculosus, or **Bladder Wrack,** is the most widely distributed of the Rockweeds. The frond or thallus is wide and flat. The air sacs, which are conspicuous, are arranged in pairs on the distinctly dichotomously dividing frond. (Fig. 61, *C* and *D*.)

1. Observe, if possible, the plants growing in their natural positions attached to the rocks. Draw an entire plant, labeling the attachment disk, stipe, frond, midrib, air sacs, and the enlarged ends of branches which bear the conceptacles containing sexual reproductive organs.

2. Thoroughly dry and pulverize some of the Rockweed, and place it in cold fresh water. The water soon takes on a brownish color, due to the special pigments which give the brown and olive colors to the plant.

Place pieces of fresh Rockweed in alcohol. The alcohol dissolves the chlorophyl and assumes a yellowish-green color.

3. Place a piece of the frond that has been preserved in alcohol between two pieces of pith and cut thin transverse sections. Mount in glycerine. Notice the differences between the centrally situated medullary cells and the cortical cells. Can you make out an epidermis? The

increase in thickness of the frond is effected by the division of the outer cells of the cortex. Draw the entire section. Test for starch. Is it present? Run Schultze's solution under the cover of another preparation. Are the cell walls composed of normal cellulose?

4. With the hand magnifier notice the distinct notch in the ends of the branches that do not bear conceptacles, *i.e.*, those that are not swollen. Then make longitudinal thin sections through the notches, using alcoholic material. Mount in glycerine. In some of the sections a well-defined four-sided apical cell will be found, surrounded by cells which have had their origin in the segmentation of the apical cells. Some difficulty will be experienced in finding the apical cell. It is by this form of cell division that the plant increases in length. Observe also in this section the distinction of medullary, cortical, and epidermal cells.

5. Make sections, both transverse and longitudinal, through the air sacs. (Fig. 61, *E.*) Do you find the same distinctions of medullary, cortical, and epidermal tissues that you have already found in the transverse and longitudinal sections of the frond? Do the structures found help you to judge how the air sacs were formed?

6. Examine with a hand magnifier the conceptacles on branches that were gathered at high tide and have hung about six hours in a cool place. The male and female conceptacles are borne on different plants in the case of *Fucus vesiculosus*. The male are distinguished from the female by an orange-colored exudation. Notice the warty appearance of the conceptacles. (Fig. 61, *M.*) Also the *ostiole*, or *stoma*, at the apex of each wart. (This is seen in section in Fig. 62, 1.) In many cases tufts of delicate hairs project from the ostioles.

7. Using alcoholic material, make thin transverse and longitudinal sections through a branch bearing male con-

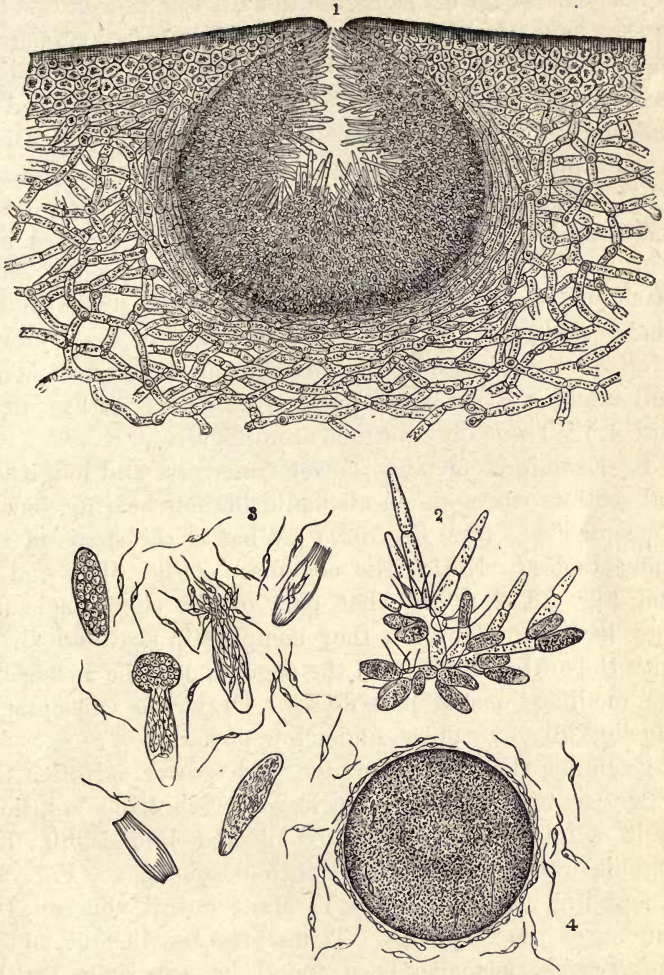


FIG. 62.—1, longitudinal section through a male conceptacle of *Fucus vesiculosus*, showing the cavity nearly filled with antheridia surrounded by paraphyses; 2, some of the antheridia and paraphyses more highly magnified; 3, ripened antheridia allowing the antherozoids to escape; 4, an egg cell like those in Fig. 63, 4, surrounded by antherozoids. All much magnified. (From Kerner and Oliver, after Thuret.)

ceptacles. (Fig. 62.) Examine with low power. What is the shape of the conceptacles? Do you find numerous hairs or *paraphyses* in the conceptacles? Do they in some cases project through the ostiole? Are they branched or unbranched? Are they unicellular or multicellular? Draw a conceptacle, showing all you can see under low power. Find small ovoid *antheridia* borne on the paraphyses, using the high power. (These are seen in Fig. 61, *b*, and Fig. 62, 2.) Draw several antheridia, showing their attachment to the paraphyses. Can you distinguish the *antherozoids* in the antheridia? Mount in sea water a drop of the orange-colored exudation mentioned above and examine it for moving antherozoids. (See Fig. 62, 3 and 4.) These observations are difficult.

8. Examine under low power transverse and longitudinal sections through an alcoholic branch bearing female conceptacles. (See Fig. 63.) What is the shape of the conceptacles? Notice the oögonia. (Fig. 61, *c* and *d*, and Fig. 63, 2.) In what part of the conceptacle are they located? How do they compare in size and shape with the antheridia? Both the oögonia and the antheridia are modifications of paraphyses. Draw the conceptacle, showing all you can see under low power.

Examine the oögonia under high power. Notice the transparent covering. Test it with Schultze's solution. Is it cellulose? In material collected in autumn, find oögonia undergoing division into oöspheres. (Fig. 61, *d*, and Fig. 63, 2, 3, and 4.) Make out, if you can, the number of the oöspheres. If material bearing the motile antherozoids has also been found, mount some of the antherozoids and oöspheres in the same drop of water and watch for the entrance of the antherozoids into the oöspheres. Draw. Does each oösphere have a nucleus?

References for Reading. — Goebel's "Classification of Plants," pp. 65–73; Carpenter's "The Microscope," pp. 554–559; "Vines' Text-Book

of Botany," pp. 263–267; Bennett & Murray's "Cryptogamic Botany," pp. 228–236; Dodge's "Practical Biology," pp. 285–296; Bower's "Practical Botany," pp. 391–408; Campbell's "Structural and Systematic Botany," pp. 42–48; Bessey's "Essentials of Botany," pp. 144–147.

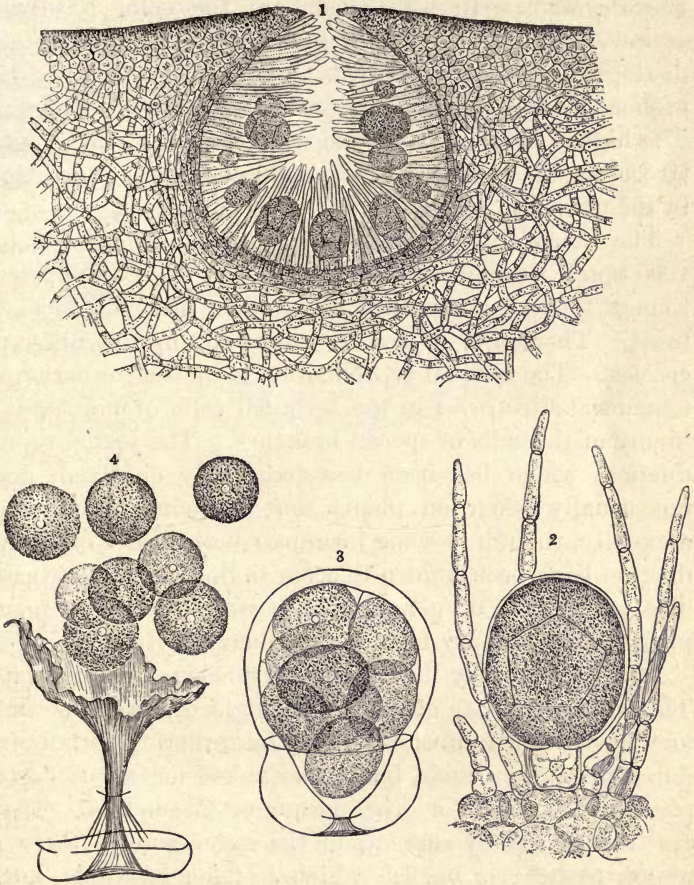


FIG. 63. — 1, longitudinal section through a female conceptacle of *Fucus vesiculosus*, showing oögonia preparing for division and surrounded by paraphyses; 2, an oögonium and several paraphyses more highly magnified; 3, an oögonium with the egg cells all ready to burst through the surrounding membrane; 4, the same after the membrane has burst and set the egg cells free. All much magnified. (From Kerner and Oliver, after Thuret.)

CLASS III. **The Red Algæ** (*Rhodophyceæ* or *Florideæ*). — These are for the most part the Red Seaweeds. A few live in fresh water. They are chlorophyl-bearing, but the green is obscured by the presence of a red coloring matter, *phycoerythrin*. In some instances the color is brown, yellow, dull white, or even green. The Red Algæ are distinguished from the Brown and Green Algæ by the higher development of the sexual reproductive organs. The higher differentiation and development of the vegetative organs also place these plants above all other Algæ in the classification.

The reproductive processes in the Red Algæ resemble very much those already described for the Coleochæteæ, though they are in general of a higher order of development. There are, of course, variations in the different species. The asexual reproduction is by the formation of nonmotile *tetraspores* in the terminal cells of branches or in any of the cells of special branches. The sexual reproduction, which has been less frequently observed, does not usually occur on plants that reproduce themselves asexually, though in some instances both modes of reproduction have been known to occur in the same individuals. The alternation of generations is well marked in many plants; the ordinary form is the gametophyte.

The plants may be either monœcious or diœcious. The antheridia may consist of a single cell each, or they may consist of a number of cells. The antheridia do not produce true antherozoids, but rather naked masses of protoplasm without cilia or other means of locomotion. They are transported by currents in the water and, as there is reason to believe, by fish which feed on seaweeds, until they come in contact with the female organ of reproduction, the *procarp*, which in many respects resembles the pistils of the Flowering Plants. The result of the fertilization of the procarp is a *carpospore*, but the variations

and complications in the process are so many that they cannot be detailed here.

Many of the Red Algæ are of great beauty on account of their red and purple colorings, and on account of their delicate, graceful forms. The Red Algæ grow in the ocean in a somewhat narrow border along the coasts. Many forms grow at some depth in the water. These deep sea forms are often the most delicate and beautiful. The seas in warmer climates abound in these plants, but the waters of colder regions, even within the Arctic circle, produce some forms.[1]

References for Reading.— Vines' "Text-Book of Botany," pp. 267–272; Goebel's "Classification of Plants," pp. 73–80; Carpenter's "The Microscope," pp. 559–561; Bennett & Murray's "Cryptogamic Botany," pp. 191–203.

[1] In places where the Red Algæ are easily obtainable, Practical Studies may be arranged on many different forms.

V.

THE FUNGI.

The **Fungi** include a very large number of chlorophyll-less saprophytic or parasitic plants. A saprophytic plant is one that lives by the absorption of decaying organic matter; a parasite lives on other living organisms, robbing them of the nourishment they have prepared for themselves. In some cases the same organisms may live either as saprophytes or parasites. Some of the Fungi are organisms of very low development; in others the development has reached a considerable degree of complication. In the higher forms the development of mycelial rhizoids is marked; these are the fine threads of the mycelium of the plant which permeate the substratum on which the plant grows and absorb from it nutrient materials; in many cases this mycelium acts as a ferment on the substances in the soil, causing their decomposition and preparing them to become food for the plant. There is in no case a tendency to the formation of leaves. The most striking characteristic of these plants is the absence of chlorophyl; this fact alone, however, does not determine their separation into a subdivision by themselves. That separation is based rather upon morphological characteristics. The plant body is a *thallus* that develops by apical growth into *root hyphæ*, the *mycelium*, or branches below the surface of the substratum on which the plant grows, and *shoot hyphæ*, or branches above the surface. A few forms that do not develop by apical growth, such as the yeast plants, for example, are classed as Fungi on account of resemblances

in other particulars, seeming to be more nearly related to these than to any other plants.

Botanists are divided in opinion as to whether the Fungi have developed independently from a common origin or are a heterogeneous group that has resulted from the degeneration of different chlorophyl-bearing plants. The weight of authority seems to be in favor of the latter view. So strong is the resemblance in the life history of many of the Fungi to algal forms, that both are placed in the same classes in some schemes of classification, the Fungi being treated simply as degenerate forms of Algæ.

Vegetative reproduction occurs in several different ways, which will be considered in connection with different plants. Sexual reproduction is known in some families, but in the majority of cases the propagation is by asexual processes. Reproduction by parthenogenesis occurs in some forms. These plants are remarkable for polymorphism, *i.e.*, they occur in different forms at different stages of their existence. Polymorphism greatly complicates the difficulties of the study of the Fungi, especially in matters of classification. Our knowledge of these plants is still very incomplete, owing to the difficulties in the way of their study and the immense number of forms. There are six classes:

CLASS I. THE CHYTRIDIEÆ.
CLASS II. THE SMUT FUNGI (*Ustilagineæ*).
CLASS III. THE MOLDS AND MILDEWS (*Phycomycetes*).
CLASS IV. THE SAC FUNGI (*Ascomycetes*).
CLASS V. THE RUSTS (*Æcidiomycetes* or *Uredineæ*).
CLASS VI. THE TOADSTOOLS AND THEIR ALLIES (*Basidiomycetes*).

CLASS I. **The Chytridieæ.** — These are very simple organisms. Alternation of generations from gametophyte to sporophyte is known in some forms. Asexual repro-

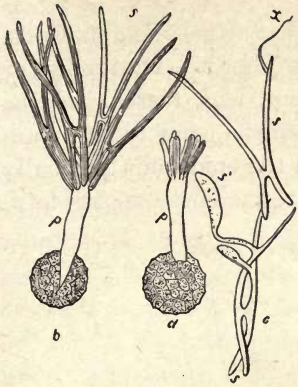
duction by zoöspores or zoögonidia also occurs. The plants of this class are found as parasites on algæ; sometimes also on Flowering Plants, and on animals and Fungi which live in the water. Relationship can be traced between members of this class and members of several of the higher classes of Fungi.

References for Reading. — Goebel's "Classification of Plants," p. 85; Vines' "Text-Book of Botany," pp. 285, 286; Bennett and Murray's "Cryptogamic Botany," pp. 344–347; Carpenter's "The Microscope," p. 565.

CLASS II. **The Smut Fungi** (*Ustilagineæ*). — The *Smuts*, or *Bunts*, are parasites on various flowering plants. They are especially common on the grasses, causing diseases which are sometimes very destructive to the cultivated grasses. The attack of the smuts is in most cases confined to some particular part of the plant, as the leaf, the stem, or the flower, on which they form spots that are brown or yellow during the early stages, but become black as the spores ripen. In some cases the smut spreads through all the different parts of the plant.

FIG. 64. — Wheat bunt (*Tilletia caries*). (Kellerman.)

The course of development of these Fungi, so far as it is known, is believed to be as follows: The black resting spore germinates into a *promycelium*, a minute plant of few cells. The promycelium bears male and female sporidia; spores from these unite and the zygospore thus formed develops into a mycelium; this mycelium produces another crop of the black resting spores. The promycelium is the gametophyte; the mycelium is the sporophyte.



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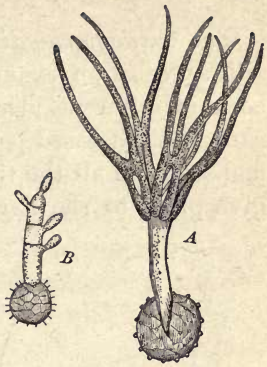

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FIG. 65. — Smut spores of *Tilletia caries*. *p*, the promycelium; *a* bears young sporidia; in *b*, the sporidia have connected by conjugating tubes to form zygospores; *c* shows a portion of the mycelium which has developed from a zygospore, and which bears a gonidium at *s'*, filled with the black spores. (After Tulasne.)

FIG. 66. — Resting spores germinating. *A*, of *Tilletia caries*; *B*, of *Ustilago receptaculorum*. (Vines.)

67

68

FIG. 67. — Oats smut (*Ustilago carbo*). (After Smith.)

FIG. 68. — Part of smutted ear of Corn. (After Tulasne.)

The *Ustilago maydis*, the smut that attacks Indian Corn, will serve as an example of these plants. It attacks the corn in different places — the stem, leaf, tassel, and the ear. The diseased portions of the corn grow to an abnormal size, and all the tissues within the epidermis gradually give place to the developing spores. These spores form

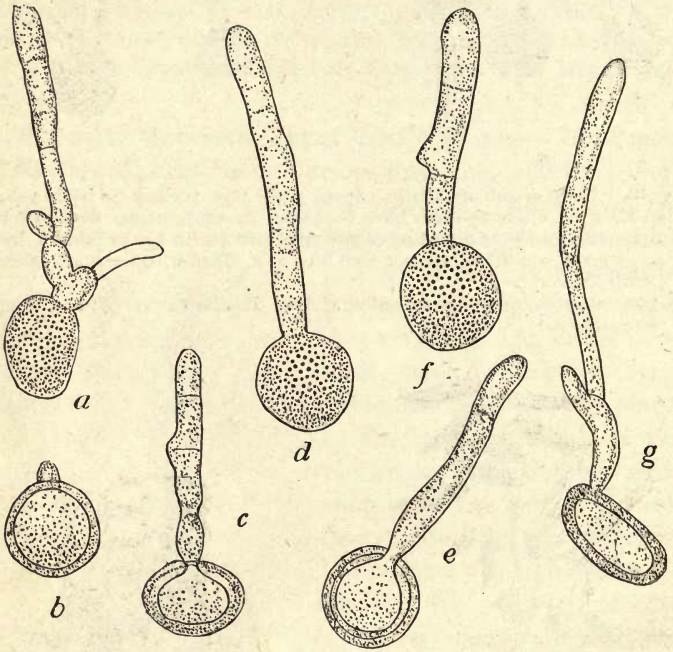

FIG. 69. — Smut spores germinating. (Kellerman.)

in such quantity that the epidermis is finally broken through, and the black, smutlike spores are scattered to the wind.

References for Reading. — Goebel's "Classification of Plants," pp. 85–88; Cooke's "Introduction to the Study of the Fungi," pp. 251–258; Vines' "Text-Book of Botany," pp. 308–310; Bennett and Murray's "Cryptogamic Botany," pp. 349–352.

CLASS III. **The Molds and Mildews** (*Phycomycetes*). — The most important plants of this class are the *Black Molds*, the *Mildews* and *Rusts*, and the *Water Molds*.

The Black Molds (*Mucorineæ*). — The *Mucorineæ* are among the commonest of the molds. They are found in abundance on moist, decaying organic matter. They are saprophytic in their nourishment. The plants grow from rootlike filaments which interlace just above or just beneath the surface of the substance on which the mold grows. This interlacing rhizoid is called a *mycelium*. From it delicate stalks or hyphæ rise tipped with enlarged masses which are sporangia filled with spores. As the spores ripen they become dark colored so that the mold, which was in the earlier stages colorless or white, turns black.

The reproduction is ordinarily asexual by the spores already mentioned. These spores dry up and are carried about in the air. They retain their vitality indefinitely. When they fall on decaying organic matter under suitable conditions of temperature and moisture, they develop at once by cell multiplication into new plants.

The sexual process of reproduction is of much less frequent occurrence than the asexual process. Two hyphæ, which must, of course, be of opposite sexes, send out projections to meet. These projections are then separated from the hyphæ that produce them by the growth of a cellulose wall. The meeting ends of the projections break away, and the contents of the two cells mingle in one. The resulting zygospore becomes encysted in a wall that is sometimes covered with curious protuberances. According to Strasburger, it is easy to raise the zygospores in moist chambers by sowing the asexual spores on thick plum juice mixed with 10 to 20 per cent of ethyl alcohol. Zygospores are also said to be formed in the spring of the year on Mucor that grows on horse manure.

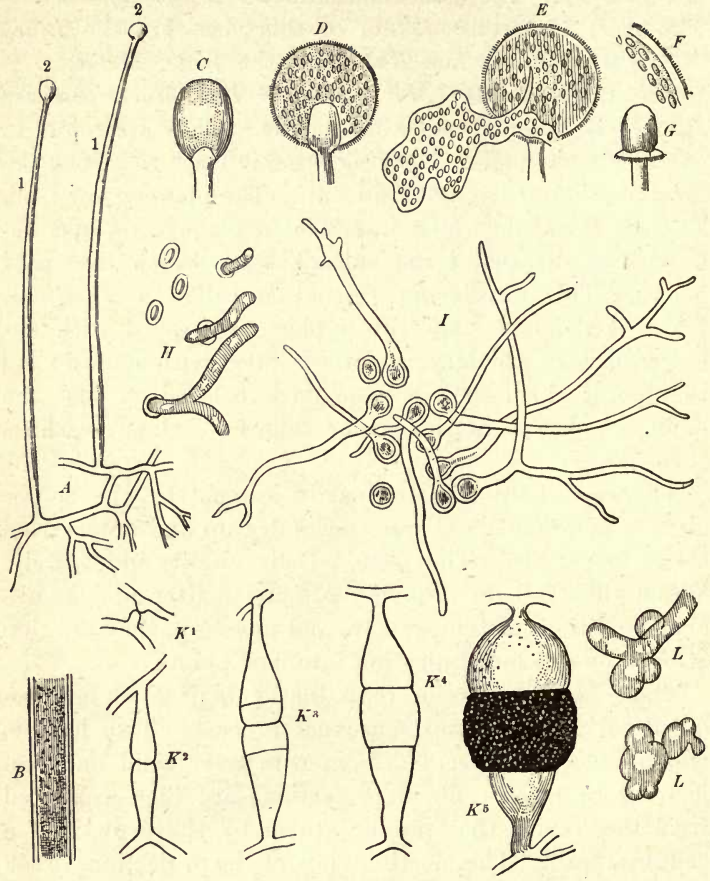

FIG. 70. — *Mucor mucedo.* *A*, a portion of the mycelium with hyphæ, 1, 1, rising from it bearing sporangia, 2, 2; *B*, a piece of a hypha, showing the structure; *C*, a young sporangium, showing the formation of the partition which cuts it off from the hypha; *D*, a nearly ripe sporangium, filled with spores, and showing the columella extending into it; *E*, a fully ripened sporangium discharging its spores and mucilage; *F*, a part of *E* more highly magnified; *G*, the columella with the collar attached; *H*, spores beginning to germinate; *I*, the same developing into mycelia; K^1–K^5, five stages in conjugation, showing the progress from the beginning of the conjugation in K^1 up to the complete zygospore in K^5; *L*, *L*, ferment cells that have developed from submerged hyphæ. (Parker.)

It is thought that the zygospore formed by some species does not develop. In the case of other species, it is known that, after a period of rest, the zygospore develops hyphæ which bear sporangia, but does not develop a mycelium. The spores borne in these sporangia develop in the asexual way into new plants. These new plants multiply in the asexual way, and it is probable that it is only after a number of generations have been produced that the sexual process is repeated to reinvigorate the plant.

A third process of reproduction sometimes occurs. By this process asexual spores, *chlamydospores*, are formed in starved filaments of the mycelium.

The black molds may be sought on decaying moist bread, on preserved fruits, and, in general, on decaying organic matter.

The molds that develop on and in the bodies of certain insects, especially on flies and caterpillars, are closely related to the black molds. The growth of these molds constitutes a disease which kills the insect. The mold continues to grow after its death. It is frequently seen fastening its victim to the walls of a room or to a window pane. The disease is communicated from one insect to another by the spores that the mold produces. The spores are borne about in the air, and if one happens to fall on a moist portion of an insect, the disease results. It is said that in the West Indies it is not at all uncommon to see insects related to our wasp flying about with plants, as large as the insects themselves, growing from some part of their bodies.

MUCOR. — PRACTICAL STUDIES.

Keep a piece of wet bread in a moist chamber until a moldy growth appears on its surface. Some of this growth will almost certainly be *Mucor stolonifer*. A

similar cultivation on fresh horse manure will produce *Mucor mucedo*. Mucor can be distinguished from other growths, in part by the greater size; in part by the black color of its spores; and in part by the fact that in young plants there are no septa except those which cut off the spherical spore-bearing knobs, the *sporangia*, from their hyphæ. In older plants septa are sparingly formed, but are far less numerous than in other growths likely to be present.

This is the first plant thus far studied among the Fungi which shows even a rudimentary differentiation into root and shoot; among the Algæ a similar differentiation has been noted in the case of the Characeæ. The aërial shoots do not show any differentiation into leaves, nor do they in any way function as leaves. They do not contain chlorophyl, and cannot assimilate carbon dioxide, even if it makes its way into them by osmotic action. The root hyphæ, on the contrary, show in quite a marked degree something that is similar to the root pressure which is characteristic of the higher plants. They take in water by osmotic action so vigorously that it is forced up into the aërial branches with energy enough, in some cases, to burst through the walls of the sporangia.

1. Tear off a very little of the growth and mount in water. Examine the mycelium (the interlacing rhizoid portions) and the hyphæ (the erect aërial stalks) for septa. Examine the sporangia which tip the hyphæ. The cell walls of the older sporangia are densely covered with crystals of calcium oxalate, which dissolve the instant they touch the water, setting the inclosed spores free, together with the mucilage which surrounds them in the sporangia. The young sporangia retain their spherical shapes.

2. Notice an ovoidal projection of the hypha into the sporangium. This is the *columella*. In some cases where

the spores have been completely set free, a ringlike projection around the base of the columella may be seen. This is the collar.

3. Run iodine solution under the cover glass. The protoplasmic cell contents are slightly stained, the cell wall is not affected, no blue color of the starch reaction is seen, but some spots of a brownish color show the presence of *glycogen* — a substance closely related to starch.

4. Treat another mount of the hyphæ with one per cent osmic acid. Granules in the protoplasm turn brown, showing the presence of oil.

5. Run Schultze's solution under the cover glass of a fresh specimen and examine the cell wall. The cell wall is stained violet. Is it composed of ordinary cellulose or fungous cellulose?

6. Make hanging-drop cultures of the spores. Cement rings of gutta percha or metal to glass slips to serve as culture chambers. Smear the tops of the rings with vaseline. Now place drops of Pasteur's solution, or of the rich juice made by stewing apricots in water and sugar, on the centers of cover glasses. Sow spores of Mucor in these drops. Invert the cover glasses carefully over the rings and press them down into the vaseline, thus forming air-tight, moist chambers. Set aside in warm places and examine from day to day to watch the development of the spores. Make drawings, showing the development at successive stages.

7. Place a piece of bread bearing a healthy growth of Mucor in a position where the light is equally strong on all sides. Observe after a time that the aërial hyphæ grow straight upwards; they are *negatively geotropic.* Observe that the root hyphæ grow downwards; they are *positively geotropic.*

8. Place a healthy growth of Mucor in a position where the light is much stronger on one side. After a time

notice that the aërial hyphæ turn towards the light; they are *positively heliotropic*.

References for Reading. — Goebel's "Classification of Plants," pp. 90–92; Vines' "Text-Book of Botany," pp. 287–289; Carpenter's "The Microscope," pp. 569–571; Bennett and Murray's "Cryptogamic Botany," pp. 335–343; Strasburger and Hillhouse's "Practical Botany," pp. 255, 256 f; Parker's "Practical Biology," pp. 158–168; Bidgood's "Elementary Biology," pp. 72–79; Bower's "Practical Botany," pp. 497–502; Huxley and Martin's "Practical Biology," pp. 420–429; Cooke's "Introduction to the Study of Fungi," pp. 226–229.

The Mildews and White Rusts (*Peronosporeæ*). — These are especially important members of the class on account of their destructive effects on valuable food plants. They may be found on the Grape as mildew, *Peronospora viticola*. One species, *Phytophthora* or *Peronospora infestans*, causes a Potato disease; another species, *Cystopus candidus*, grows on Lettuce, Radish, and Shepherd's Purse; another on Spinach, *Peronospora effusa;* another, *Cystopus bliti*, grows on Pigweed in late autumn. The rapid spread of these diseases is caused by the dissemination of the spores by the wind. The spores fall on the plants, and develop, sending their rhizoids through the stomata or the thin, moist epidermis of the leaves, developing *haustoria* — a special form of mycelium growth — in the

FIG. 71. — Diseased Potato leaf. A Potato leaf infected with downy mildew, *Peronospora infestans*. The figure shows portions of the leaf covered with a dense mass of the Fungus which when mature turns the leaf dark brown or black. (After Marshall.)

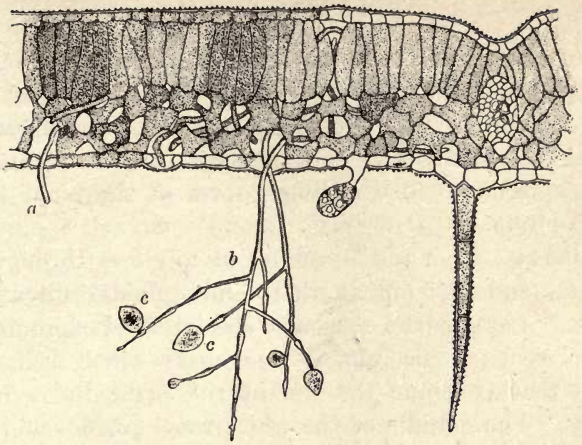

FIG. 72. — Section of Potato leaf, showing development of mildew, *Peronospora infestans*. The figure shows the mycelium, *a*, interlaced among the cells of the potato leaf; the stalk, or hypha, *b*, passing through a stoma; and the gonidia, *c*, *c*, which bear the spores. (After Marshall.)

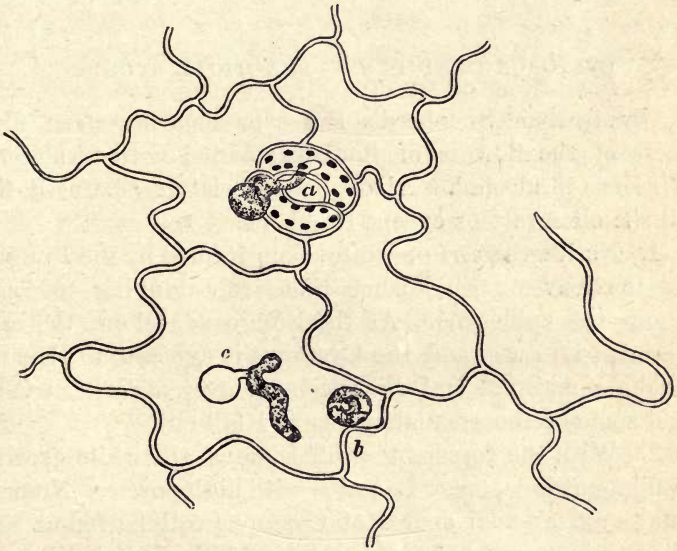

FIG. 73. — Surface of Potato leaf greatly magnified, showing germinating spore entering breathing pore at *a*, and going through epidermis at *c*. Another spore that has not begun to germinate is seen at *b*. (Ward.)

cells of the plant on which they are parasitic. Some of these plants live, under different conditions, either as parasites or saprophytes. Some grow in the dead bodies of animals. An alternation of generations occurs, at least in most species. The ordinary form of the plant is the gametophyte.

Stalks rise from the mycelium of mildews through the stomata, and develop at their ends gonidia filled with spores. Late in the season a special kind of gonidium, known as a perithecium, is developed which bears the spores that continue the life of the plant through the winter. The gonidia of the white rusts are developed in chainlike rows just below the epidermis. The oögonia and antheridia of the sexual reproduction are also produced beneath the epidermis in the intercellular spaces of the host plant, on branches of the stalks or hyphæ.

CYSTOPUS CANDIDUS. — PRACTICAL STUDIES.

Obtain some Shepherd's Purse or some Purslane, and some of the flowers of Radish, affected with Cystopus. Preserve in alcohol. Alcoholic material may be used for all the observations except Number 3.

1. Notice the *sori* or white spots formed by the Fungus on the leaves. Find some that are beginning to form under the epidermis. As the Fungus develops, the epidermis gives way and the Cystopus is exposed to the air. Shake a matured and dry specimen over a dark surface, and some of the asexual spores will fall out.

2. With the forceps tear off some of the white growth and mount in water. Examine with high power. Numerous ovoid asexual spores of Cystopus will be found. If the specimen was not too dry, some will be found still connected in short chains. Do you find chlorophyl bodies? Test for starch. Is it present?

3. Place some fresh leaves, bearing Cystopus, in a warm, moist chamber over night. In the morning mount some of the white growth in water. After an hour or so examine for motile zoöspores which have escaped from the spores. After watching their motion for a time, run iodine solution under the cover glass and determine whether or not the motion is produced by cilia. Draw. The zoöspores remain motile only a short time. They then grow by cell division and produce new plants of Cystopus.

4. Under the cover of a preparation similar to that in Number 2 run Schultze's solution. Is the cell wall composed of ordinary or of fungous cellulose?

5. Macerate in caustic potash for some time small pieces of the leaf bearing the Cystopus, taking care to put in as little as possible of the healthy parts of the leaf. Then tease out the Cystopus in a drop of water on a glass slip, add a drop of Schultze's solution, cover and examine. Find tangled masses of the mycelium which have been torn out of their positions in the cells of the host plant. Do you find septa? Draw a portion of the mycelium, showing the hyphæ and the chains of asexual spores in position on the hyphæ.

6. Place a leaf bearing sori between two pieces of pith and cut delicate transverse sections through the sori, keeping the pith and razor wet with alcohol. Examine some of the sections, applying Schultze's solution. If the sorus was young, the gonidiophores (stalks bearing the asexual spores) will be found just below the epidermis of the host. If the sorus was old, the epidermis of the host will have broken away and its edges will be turned out. Look for *haustoria*, the minute transparent globular suckers which the Cystopus sends into the cells of the host to rob them of their contents. These will be most easily found in the youngest sori. Draw several, showing their attachment to the mycelium. If they cannot be

found in the sori on the leaves, look for sori on the pedicels of the youngest flowers of Radish ; section, and examine. It is not always easy to obtain material for this and the following observation.

7. Stain thin sections of the diseased flowers of Radish with Schultze's solution and examine for the organs of the sexual reproduction. The nearly spherical oögonia and antheridia take a deep red stain. The antheridia are smaller than the oögonia. Draw a typical pair. Notice the ova in the oögonia. Find also in mature oögonia the oöspores which result from the fertilization of the ova. These oöspores are the resting spores. Protected by the greatly thickened tissues of the flowers, they lie dormant through the winter. In the spring they are set free by the decaying of the flowers, are scattered about by the wind, and falling on favorable plants produce new crops of Cystopus.

It may in some cases be possible to see a fine tube connecting the antheridium with the oögonium. Were the antheridium necessary in all cases for the fertilization of the egg cell, the connecting tube would be seen in many cases, but it is probably the fact that fertilization is in most cases by parthenogenesis.

References for Reading. — Goebel's "Classification of Plants," pp. 92–96; Vines' "Text-Book of Botany," pp. 291–293; Cooke's "Introduction to the Study of Fungi," pp. 230–232; Bessey's "Essentials of Botany," pp. 139–143; Bennett and Murray's "Cryptogamic Botany," pp. 323–332; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 43–51; Bower's "Practical Botany," pp. 491–496; Strasburger and Hillhouse's "Practical Botany," pp. 256 f–258; Carpenter's "The Microscope," pp. 567, 568; Sachs' "Physiology of Plants," pp. 370–390.

The Water Molds (*Saprolegnieæ*). — These are saprophytic or parasitic plants that grow on the bodies of fishes in the water, and in the case of a few species in the living tissues of animals. It is this plant that causes a disease

which is very destructive to salmon. These plants closely resemble Vaucheria in the process of reproduction, both sexual and asexual. The alternation of generations is well marked. The plant *Achlya prolifera* is a type. It may be easily raised by placing dead flies in water.[1]

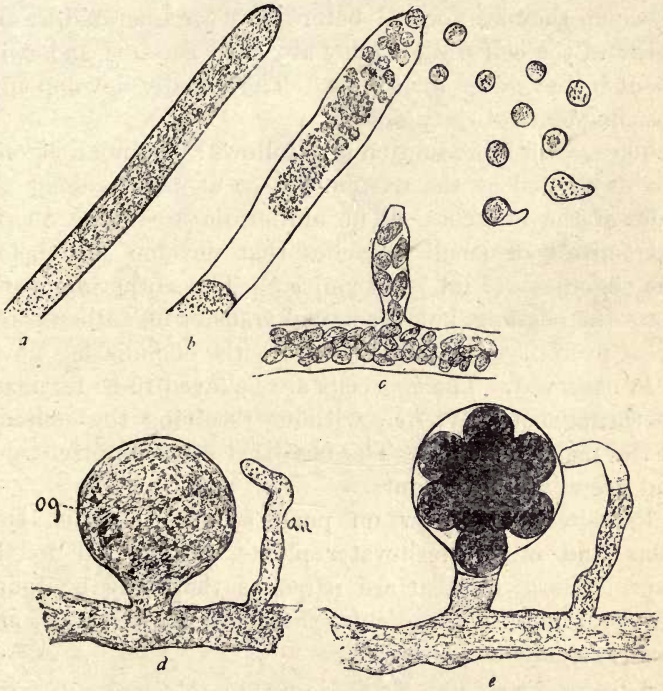

FIG. 74.—Water Mold. *a*, end of filament, showing the partition cutting off the protoplasm near the end from the rest of the filament; *b*, same, with protoplasm divided into escaping zoöspores; *c*, zoöspores inside a filament; *d*, filament showing oögonium and antheridium; *e*, filament after fertilization of oögonium. Magnified.

After a few days, transparent or whitish branched filaments grow from various parts of their bodies. In general outline the tubular partitionless filaments resemble

[1] Arrange Practical Studies of this plant.

the branching filaments of Vaucheria. In the methods of reproduction the resemblance is also striking. The asexual reproduction is by the formation of zoöspores or zoögonidia, which develop in special cells that become cut off from the rest of the filament by transverse partitions. The zoöspores are flagellated and swim about in the cell in which they are formed before they are liberated by the decay of the cell wall. They are then set free and swim about in the water for a time. They finally develop into new filaments of the plant.

The sexual reproduction is as follows: Globular oögonia are developed at the extremities or at points along the sides of the branches. The antheridia are borne on the extremities of small branches that develop just below the oögonia. (Fig. 74, *d* and *e*.) The antheridia penetrate the oögonia, but the actual transfer of antherozoids, or of protoplasm in any form, into the oögonia has never been observed. The egg cells are believed to be fertilized parthenogenetically, *i.e.*, without receiving the contents of the male elements. The fertilized eggs are discharged and grow into new plants.

Parasites that grow on pond scums, Desmids, Diatoms, and other fresh-water plants, are related to the Saprolegnieæ, as also are parasites that may be found on the Plantain, the Mints, the Evening Primrose, and some leguminous plants.

References for Reading. — Vines' "Text-Book of Botany," pp. 293, 294; Goebel's "Classification of Plants," pp. 96–99; Cooke's "Introduction to the Study of Fungi," pp. 233, 234; Bennett and Murray's "Cryptogamic Botany," pp. 332–334; Bessey's "Essentials of Botany," pp. 136–139; Carpenter's "The Microscope," p. 569.

CLASS IV. **The Sac Fungi** (*Ascomycetes*). — The distinguishing feature of this class is the formation of spores in sacs or *asci*. These sacs are club shaped or globular. The class is a large one and includes many common plants,

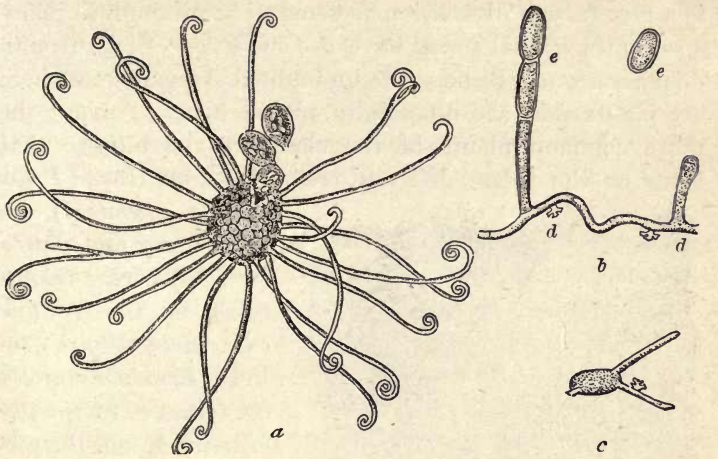

FIG. 75. — Grape Mildew, *Uncinula ampelopsidis*. *b*, a small piece of mycelium bearing haustoria at *d*, *d*, and spores at *e*; *c*, a spore germinating; *a*, a perithecium, *i.e.*, a spore case that develops late in the season. (After Scribner.)

which grow as parasites on living plants or as saprophytes on decaying plants. Besides the characteristic reproduc-

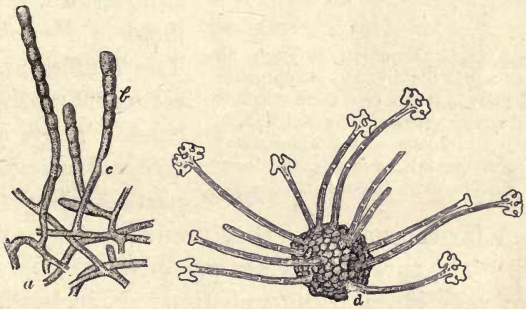

FIG. 76. — Apple Powdery Mildew. *a*, mycelium bearing hyphæ, *c*, which in turn bear chains of summer spores, *b*; *d*, perithecium or winter spore case. Magnified. (After Burrill.)

tion by ascospores, many of these plants bear ordinary spores in gonidiophores that are raised on stalks. There

is a recognized alternation of generations, though in many species the sexual forms have become suppressed through degeneration. Besides the undoubted Ascomycetes there are plants that are doubtfully placed here. Among the more common plants of the class are the blights that grow on the Lilac (*Microsphæra friesii*), on Hops (*Podosphæra castagnei*), on the Cherry and Apple (*Podosphæra tridactyla*), on the Willow (*Uncinula adunca*), on Peas (*Erysiphe martii*), on Grasses (*Erysiphe graminis*), on Buttercups (*Erysiphe communis*), on Celery (*Cercospora apii*). Other members of the class are the common molds — the herbarium mold (*Eurotium*), the blue mold (*Penicillium*). The **Truffles** are interesting members of the class. They are natives of Europe, in some parts of which they are cultivated for the market; they occur to some extent in America. The spore fruits are produced in the ground. They are very large, being sometimes six inches in diameter. These are the edible parts, and they are highly prized as an article of food. One of the doubtful orders includes ordinary yeast (*Saccharomyces cerevisiæ*) and other related yeasts. Here also belong certain Lichen-forming Fungi.

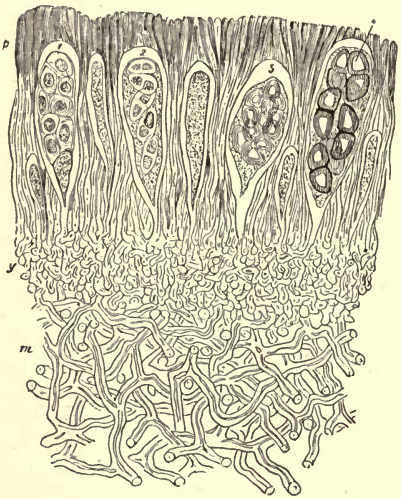

FIG. 77. — A vertical section through an apothecium of the Lichen, *Anaptychia ciliaris*, showing the spores in various stages of advancement in the asci, 1, 2, 3, 4; *p*, the paraphyses of the hymenium; *y*, the subhymenial layer; *m*, the loose fungal constituents. (Goebel.)

References for Reading. — Goebel's "Classification of Plants," pp. 100–114; Vines' "Text-Book of Botany," pp. 298–303; Bennett and Murray's "Cryptogamic Botany," pp. 353–381; Bower's "Practical Botany," pp. 470–472; Strasburger and Hillhouse's "Practical Botany," pp. 269–271; Cooke's "Introduction to the Study of Fungi," pp. 164–172; Bessey's "Essentials of Botany," pp. 155–165; Carpenter's "The Microscope," pp. 571–574.

The **Lichens**, often popularly mistaken for Mosses, grow everywhere on stones, trees, fences, and the ground. They are for the most part Sac Fungi; a few belong with the Toadstools. Until within recent years they were thought to be independent plants, but they are now known to be parasites of a very peculiar kind. The plants upon which they grow belong to the lowest orders of the green plants, such as Protococcus, Chroöcoccus, Glœocapsa, and Nostoc. The Fungi grow in such a way that they entirely envelop the host plant, which seems to gain a decided advantage from the association, so that it often grows in places where it could not possibly exist without the protection and moisture afforded by the enveloping Fungus. Such growth of plants in interdependence upon one another is known as *symbiosis* or *commensalism*.

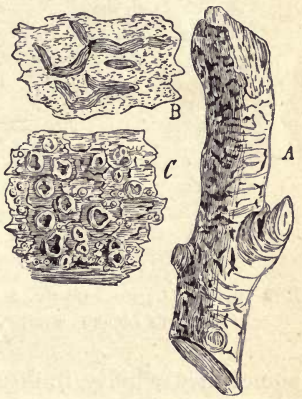

FIG. 78. — *A*, *Graphis elegans*, crustaceous Lichen; *B*, a small portion of the same more highly magnified; *C*, *Pertusaria Wulfeni*, also a crustaceous Lichen. (Goebel.)

The thallus of the Lichen sometimes clings closely to the supporting surface. Such Lichens are called *crustaceous*. (Fig. 78.) Sometimes the thallus is flat, but has curled or crisped edges. Such Lichens are called *foliaceous*. (Fig. 79, *B*.) Sometimes the Lichens

are attached to the supporting surface by a very small area and rise from it with branching treelike forms. Such Lichens are called *fruticose*. (Fig. 79, *A*.)

The sexual reproduction is known to exist in Lichens, — at least in some species, — but is as yet imperfectly understood.

By the asexual method of reproduction, spores are produced in sacs. (Figs. 77 and 81.) These sacs are

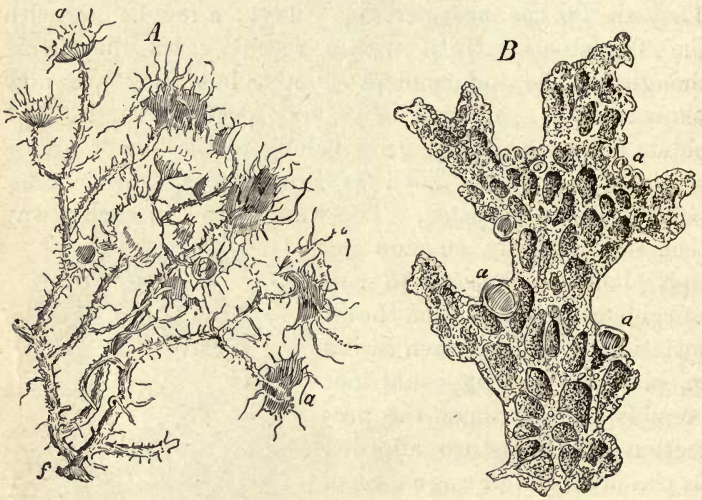

FIG. 79. — *A*, *Usnea barbata*, a fruticose Lichen; *B*, *Sticta pulmonacea*, a foliaceous Lichen; *a*, *a*, *a*, in both figures, apothecia. (Goebel.)

sometimes wholly inclosed in the tissues of the Lichen; sometimes they are grouped in circular masses that show conspicuously as disks on the surface of the thallus. (These may be seen in Figs. 78, 79, and 82.) They are to be studied by making sections through these disks.

Material for practical work may be kept in the dry condition indefinitely; upon being wet, the dried Lichen resumes its active existence.

THE LICHENS. — PRACTICAL STUDIES.

1. Observe Lichens in their natural locations on trees, stones, fences, and the ground. Some, the crustaceous Lichens, are so closely attached to the substratum that they cannot be removed entire. Others, the foliaceous, are attached in only a few places by rootlike processes called *rhizines* (Fig. 80, *r*, *r*); the edges of the crustaceous Lichens are more or less curled or crinkled. Still others, the fruticose Lichens, are attached in only one place, and rise in branching shrublike forms from their substratum.

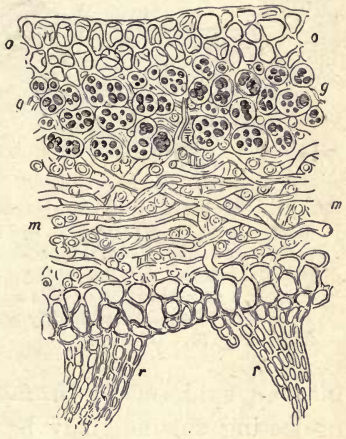

FIG. 80. — A transverse section through a foliaceous Lichen, not passing through an apothecium; *o*, epidermal layer of the upper side; *g*, the gonidial layer; *m*, the loosely arranged algal layer; *r*, *r*, rhizines. (Goebel.)

2. Find Lichens bearing disk or cup-shaped spots. These are the fructifications, the *apothecia*. They will be more minutely studied later. At present find as many different kinds of Lichens bearing apothecia as possible. (See Figs. 78, 79, 82.)

3. Place pieces of any foliaceous Lichen that is not gelatinous between pieces of pith, and cut vertical sections not passing through an apothecium. Mount in water. The water causes the tissues to swell to such an extent that it is not easy to make sections which will show all the structures fully. A number of sections should therefore be cut and the most favorable selected.

Beginning at the upper surface, observe that the tissues have become differentiated to form a more or less colored

outer layer or epidermis. Beneath the epidermis is a layer of dense, colorless, fungal tissue. Below this is a layer containing green cells of the algal constituents of the Lichens. These green cells were formerly thought to be the fructifications, and were called *gonidia*, which name is still retained. Notice that the hyphæ of the Fungi are in close contact with the algal cells. Passing below the algal layer, the fungal tissue becomes looser, and the interlacing, branching, colorless tubular cells of which it is composed show more clearly their fungal nature. On the lower side of the section the tissue passes again into an epidermis. In favorable places the threadlike, projecting rhizines may be seen. Repeat these observations on sections cut from a piece of Lichen that has been kept in alcohol. Keep the specimen wet with alcohol while cutting the sections, and mount the sections in alcohol. (Compare Fig. 80.)

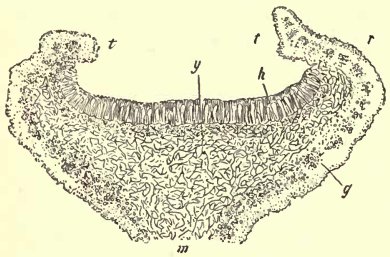

FIG. 81. — Section through the apothecium of *Anaptychia ciliaris*. *m*, the algal portions; *g*, the gonidial portions; *h*, the hymenium; *y*, the subhymenial layer. A small portion of this apothecium may be seen more highly magnified in Fig. 77. (Goebel.)

4. Cut transverse sections of the stem portion of the fruticose Lichen *Usnea barbata*. (Fig. 79, *A*.) This Lichen grows in abundance on old trees. It may be recognized by its decidedly shrublike form, its round stem, its conspicuous apothecia, which are flattened expansions of the thallus, and its general bristling, bearded appearance. Mount the sections in water. Observe how closely the cross section of the stem of this Lichen simulates the stems of the higher plants. On the outside the fungal tissue is differentiated to resemble an epidermis; then comes a layer of

dense fungal tissue which corresponds to a cortex; inside this is the green, gonidial layer, extending completely around the stem; inside the gonidial layer the fungal tissue becomes looser; in the center of the stem the fungal tissue again becomes dense and of a more or less reddish color. Repeat the observations on sections of alcoholic material.

Remembering that all green, chlorophyl-bearing plants require the sunlight, is the position of the Protococcuslike algal constituents, as observed in the foliaceous and fruticose Lichens in this and the preceding section, favorable for their healthy development? Remembering that these Algæ require moisture for their growth, is their envelopment in the tissues of the Fungus favorable for their development?

5. Treat sections, not passing through apothecia, of foliaceous and fruticose Lichens with iodine solution. Do you find any indications of the presence of starch in the fungal portions? In the algal portions?

6. In the Lichens thus far studied the algal constituents have occupied a definite position separated from the fungal constituents. Such Lichens are called heteromerous. In certain gelatinous Lichens the algal constituents are scattered without definite arrangement throughout the thallus. Such Lichens are called homoiomerous. Make and examine sections of such Lichens, which may be found in moist locations on the ground and on rocks. (See Fig. 83.) Treat with iodine and with Schultze's solution.

FIG. 82. — *Collema pulposum*, a gelatinous Lichen. (Goebel.)

7. Make vertical sections through the apothecia of *Usnea barbata*. Sections cut in paraffin from material fixed in picric acid or corrosive sublimate, stained in hæmatoxylin or fuchsin, and mounted permanently in

balsam or glycerine, are best for this observation.[1] Sections cut from fresh material and mounted in water or glycerine will do. On the upper portion of the apothecium, just below the epidermis, find ovoidal cells, the *asci*, arranged perpendicularly to the surface, large end outward; each ascus, or sac, contains a number of spores. Between the asci are long narrow cells, also arranged perpendicularly to the surface; these are *paraphyses*. The asci and paraphyses together make up the *hymenium*. (Compare Figs. 77 and 81.) Just below the hymenium is the subhymenial layer, composed of dense, interlacing fungal elements. Below this is the layer bearing the algal constituents, which extend entirely around the section. Inside the algal layer the fungal constituent becomes looser for a space, but in the central portions again becomes dense.

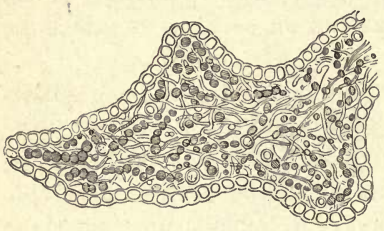

FIG. 83. — A vertical section through the gelatinous Lichen, *Leptogium scotinum*, showing the algal constituents scattered throughout the entire thickness of the thallus. (Goebel.)

Treat a section passing through the apothecium, made from fresh material and mounted in water, with very dilute iodine solution. The tissues of the hymenium take on a blue color — the starch reaction. Treatment with Schultze's solution gives a similar result. The cell walls of the hymenial tissues are composed of modified cellulose, known as starch cellulose. Do iodine solution and Schultze's solution give the blue color in other portions of the fungal constituents? In the algal con-

[1] For the processes used in the preparation of vegetable specimens for sectioning and mounting consult the author's "Practical Methods in Microscopy," Chap. VII.

stituents? The production of the spores is a result of a conjugation, the study of which is too difficult for beginners. Male gametes, *spermatia*, conjugate with female gametes, *trichogynes*, inside the tissues of the hyphæ. The resulting apothecia emerge to the surface, where the spores are exposed directly to the open air in gymnocarpous Lichens, or are ejected through minute orifices in the angiocarpous Lichens when the dried apothecium is wet.

The spores germinate into hyphæ, but this development soon ceases and the hyphæ die, unless they come in contact with cells of the Algæ with which they are associated in forming the Lichen. When the hyphæ and the Algæ come together, the development of each goes on vigorously. The Algæ, protected and furnished moisture by the Fungus, take in carbon dioxide from the air and mineral elements from the moisture. The rhizines of the Fungus, in the case of many foliaceous Lichens, take up mineral matters from the substratum, and even decompose the substance of rocks and convey to the Algæ the inorganic materials necessary for the formation of protoplasm. As the protoplasm increases, the cells enlarge and multiply by cell division. At the same time the parasitic Fungus draws abundant sustenance from the well-nourished cells of the Algæ.

8. Besides the reproduction by spores, there is also a vegetative reproduction by means of *soredia*. Select a specimen of *Usnea barbata* that bears few or no apothecia, and that appears powdery at least in places. Material secured as soon as it has dried after a rain is best. Brush some of the powder into a drop of water on a slide, and examine under high power. Single algal cells and groups of algal cells associated with fungal hyphæ will be seen. These are the soredia in their elementary stages. More advanced stages will also be found. In these the hyphæ

have grown towards each other on what was the outer end of the soredium, as it grew on the parent Lichen, forming an arch over the algal portions. The soredia separate from the Lichens as they dry after rain, and are then blown about by the wind. This mode of distribution of the soredia and spores explains the abundance and wide distribution of Lichen growths. (See Fig. 84).

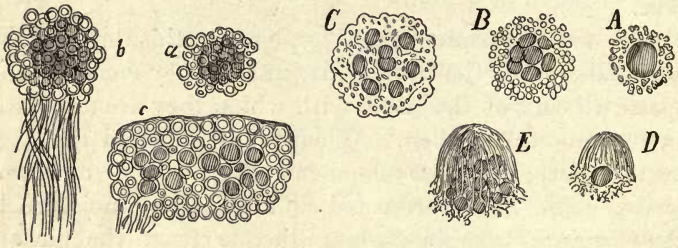

FIG. 84. — *A*, *B*, *C*, soredia of *Usnea barbata* in their earliest stages; *D*, *E*, the same developing arched growths of the fungal constituent; *a*, *b*, *c*, soredia of *Physcia parietina* in different stages of development. (From Goebel, after Schwendener.)

The arching growth of the hyphæ over the Algæ at the outer end of the soredium also illustrates the typical method of growth in much the largest number of heteromerous Lichens. The Fungus grows in advance, and leads the way for the Algæ. In a few heteromerous Lichens the Algæ grow in advance of the Fungi. In the homoiomerous Lichens it has not yet been determined whether the Fungus or Alga grows in advance.

References for Reading. — Goebel's "Outlines of Classification," pp. 114–126; Sachs' "Physiology of Plants," pp. 391, 514; Vines' "Text-Book of Botany," pp. 319–320; Bennett and Murray's "Cryptogamic Botany," pp. 318–322; Bower's "Practical Botany," pp. 473–480; Bessey's "Essentials of Botany," pp. 165–169; Strasburger and Hillhouse's "Practical Botany," pp. 202–270; Carpenter's "The Microscope," pp. 576–579; Geddes' "Chapters in Modern Botany," pp. 114–119.

The **Black Fungi** (*Pyrenomycetes*) are important plants of this class. Familiar examples of these are the black knots common on Cherry and Plum trees. These plants produce filaments which lie dormant under the bark until the spring of the following year, when they develop rapidly, producing a disease of the branch on which they grow by causing an abnormal development of the bark. The gonidia formed by the asexual process may be studied on the surface edge of thin sections of the knot made in the late spring; the ascospores of the sexual process may be studied in thin sections cut in the winter. The spores may then be seen in their sacs, and by the sides of the sacs slender filaments, the so-called *paraphyses*.[1]

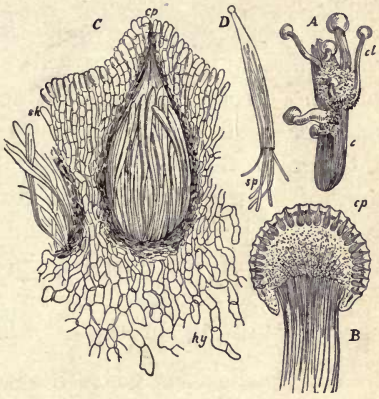

FIG. 85. — *Claviceps purpurea*, the Fungus that produces ergot on Rye. *A*, a sclerotium or ergot that forms in the heads of Rye, bearing seven stromata or fructifying heads; *B*, one of these heads seen in section, showing the perithecia, *cp*, which bear the asci; *C*, a perithecium containing asci more highly magnified; *D*, a single ascus discharging its spores, *sp*. (From Sachs, after Tulasne.)

There are many species of Black Fungi. The black spots that develop on the leaves and bark of different kinds of trees, and *ergot*, a parasite on heads of rye and other grains, are among them.

References for Reading. — Vines' "Text-Book of Botany," pp. 301, 302; Bower's "Practical Botany," pp. 481–483; Cooke's "Introduction to the Study of Fungi," pp. 197–220; Bessey's "Essentials of Botany," pp. 163–165.

[1] Have on hand material collected at the different seasons, and preserved in alcohol or formalin. Arrange Practical Studies.

The **Saccharomyces, or Yeast Plants,** are by some authorities classed with the Bacteria. Their proper place in the scheme of classification has not been determined. The formation of ascospores under certain conditions of existence, and their resemblance in other respects to the Ascomycetes, are strong reasons for placing them in this class.

The yeast cell is ovoidal in shape. It consists of a very delicate transparent wall of cellulose, inclosing protoplasm. More or less distinct, noncontractile vacuoles may be seen. The vacuoles are simply spaces in the interior of the cell not filled by the protoplasm. They are, of course, filled with fluid. In some cells highly refractive particles of fat and other granules, which are the result of the nutritive processes of metabolism, are found. The nucleus can be seen only after the use of special staining processes which have been discovered recently.

YEAST. — PRACTICAL STUDIES.

Dissolve a yeast cake in water to which some sugar has been added, or better in Pasteur's solution. After it has been growing for some hours, place a drop of the fluid on a glass slip and cover lightly with a cover glass. Examine with high power.

1. Observe the prevailing ovoidal shape of the highly transparent cells, being careful not to confound starch granules that may be present with the yeast cells. If the yeast is in an actively growing condition, the characteristic mode of reproduction by *budding* will be seen. Budding is a modification of cell division in which one of the newly formed parts is smaller than the other. The small bud rapidly grows to the full size of the mother cell and separates from it. The plant is, therefore, unicellular, though retardation in the separation of the daughter cells,

due to the fact that the outer coating of the cell wall is mucilaginous, frequently gives rise to chains or groups of cells. Draw a single cell and groups of cells showing buds.

2. Sow thin layers of yeast that is in the active budding condition on slabs of plaster of Paris or on freshly cut surfaces of potato or turnip. The surface portions of a cultivation of yeast obtained from a brewery are best for this observation. Keep under bell jars, adding distilled water to the containing dish from time to time to prevent the yeast from drying up. It is best to prepare a number of these cultivations, as bacterial and fungoid growths are likely to interfere. Examine mounts of the yeast from the surface daily, after about a week, until the contents of some of the cells are seen to have undergone division into two or four parts. The yeast cells are starved, the vacuoles become larger and more numerous, and, as a last effort to preserve life, the protoplasm divides into what are virtually resting spores. These divided cell contents indicate another method of reproduction. They are known as *ascospores* or sac spores. They are called sac spores because they are contained within the wall of the mother cell as in a sac. Draw a typical cell.

3. Make a mount of actively growing yeast. Observe the vacuoles — clear spaces empty of protoplasm — in the central part of many of the cells. Between the vacuoles and the surfaces of the cells observe the protoplasm, which is quite clear in many of the cells; in others, it presents a granular appearance, due to the presence of minute particles of oil and granules of proteinaceous matter.

4. Study the cell wall. Press firmly on the cover glass, and thus burst some of the cells. Observe the colorless cell walls left empty of their contents. Run a drop of magenta under the cover glass. The cell wall is

not stained by this dye, but the cell contents take a pinkish tinge.

Prepare another mount of the yeast, burst some of the cells, and run iodine solution under the cover glass. The cell wall is rendered more distinct, the protoplasm is slightly colored, but none of the particles are stained blue. Starch is therefore not present, consequently chlorophyl is absent. These reactions are all more distinct, if, instead of using a fresh preparation, a thin layer of the yeast is allowed to dry on the cover glass. A drop of water is then placed on it, the cover glass is put in position on a glass slip, and the iodine is applied.

Make another dry preparation on a cover glass, treat with 70 per cent sulphuric acid for a few minutes, wash out the acid with water, stain with dilute iodine solution, and mount. The cell wall will be beautifully distinct in some of the cells because of the shrinking of the protoplasm.

The cell contents may also be made to shrink by mounting some fresh yeast and running a drop of a ten per cent solution of common salt in water under the cover glass. The shrinking of the cell contents is due to the fact that the solution used passes freely through the cell wall itself, but does not pass through the thin layer of the protoplasm that lines the cell. This treatment is called *plasmolyzing* the cell.

5. Prepare a dry layer of yeast on a slide and stain it with Schultze's solution. This treatment stains the cell walls of higher plants blue or violet, but gives a yellowish-brown color to the cell walls of the Fungi. The material of the cell wall is in this case fungous cellulose. That fungous cellulose is closely related to ordinary cellulose is proved by the fact that, after it has been treated with dilute caustic potash for a long time, it gives the usual blue or violet reaction with Schultze's solution.

6. Examine for the nucleus. Prepare a dry layer of yeast on a cover glass; fix the cell contents by allowing the cover glass to remain in a strong solution of picric acid for twenty-four hours. Wash thoroughly in water to remove the picric acid, and stain in ammonia hæmatoxylin, which may be prepared by shaking some of the hæmatoxylin crystals in distilled water to which a minute drop of aqua ammonia has been added. Allow this stain to act for several hours, but do not let it dry on the cover glass. Wash thoroughly in water and mount. The nucleus will now be seen in the center of the cells as a small round mass more deeply stained than the rest of the cell.

7. Prepare two test tubes containing actively growing yeast. Wrap one in opaque paper. Stand the two tubes in the bright light of a window. Prepare two other tubes in the same way and stand in the diffused light of the back part of the room. Does the presence or absence of light affect the growth of the yeast?

8. Grow yeast in Pasteur's solution in a flask, connecting the flask by means of a delivery tube with a beaker of clear lime water. After a time the lime water becomes cloudy because of the formation of carbonate of lime occasioned by the union of carbon dioxide, given off by the growing yeast, with the lime water (*calcium hydroxide*). Distil what remains in the flask until about one fifth of it passes over. Mix this distillate with potassium carbonate and distil again. Observe a peculiar streakiness on the neck of the retort; this is characteristic of alcohol. This distillate may further be proved to be alcohol by its odor, by the fact that it will burn, and by the green color and fruity odor produced when a little of it is boiled after the addition of a few drops of a solution of potassium bichromate and of sulphuric acid. A substance which has the power to effect decomposition as the

yeast has decomposed the Pasteur's solution is called an organized ferment.

References for Reading. — Bidgood's "Elementary Biology," pp. 27–44; Parker's "Elementary Biology," pp. 71–81; Huxley and Martin's "Practical Biology," pp. 377–388; Dodge's "Practical Biology," pp. 28–39; Carpenter's "The Microscope," pp. 574, 575.

PENICILLIUM. — PRACTICAL STUDIES.

Penicillium glaucum is one of the most common molds. It is found on a large variety of substances that are exposed to the air as a blue or green mold. It may be raised for study by sowing its spores on Pasteur's solution or on a decoction of vegetable matter, such as was used in studying Bacteria. In fact, either of these solutions, left exposed to the air, will generally bear the mold after a few days. It first appears as minute tufts of cottonlike filaments. These tufts enlarge in diameter and grow thicker in the center. The inner portions gradually change to blue, and finally to sage green, so that a well-developed spot has a green center, surrounded by a ring of blue and a second peripheral ring of white.

Penicillium glaucum resembles Eurotium somewhat in its structure, but is readily distinguished from it by its smaller size, by the color, and by the fanlike arrangement of the spores in the heads. The formation of spore fruits is known to occur, but their study is difficult for beginners.

1. Cultivate some Penicillium on Pasteur's solution or hay decoction. Carefully transfer one of the smallest spots to a glass slip, keeping it right side up. Do not use a cover glass. Examine with the lowest power. Notice the mycelium, composed of interlacing filaments; the aërial hyphæ rising erect into the air; and the submerged hyphæ descending into the nutrient solution.

FIG. 86.—1, *Mucor mucedo*; 2, longitudinal section of sporangium of same; 3, fruit formation in same (see p. 125); 4, *Aspergillus niger*; 5, longitudinal section of a sporangium of same (related to *Eurotium*, see p. 155); 6, fructification of *Penicillium crustaceum* (after Brefeld); 7, fruit formation of *Aspergillus* (after Eidam); 8, *Penicillium crustaceum*; 9, sporangium of same (Kerner and Oliver).

2. With the forceps tear away some of the white filaments of the outer ring. Mount them in 30 per cent alcohol and examine under high power. What is the shape of the distal end? Do these white filaments bear gonidia? Are there septa across the filaments? Treat with Schultze's solution. Are the cell walls composed of ordinary or of fungous cellulose?

3. Mount some of the filaments taken from the blue ring in 30 per cent alcohol. Compare the distal ends of these with those from the white ring. Do these bear gonidia? Make another mount from the central green portion. State how the distal ends of these compare with the distal ends of filaments from the blue and white rings. Compare the septa in the three mounts. Is Penicillium a unicellular or multicellular plant?

4. Examine the gonidia. Show by a drawing the arrangement of the spores. To the naked eye the spores in mass appear blue or green. Can you distinguish either of these colors under the microscope? The color is not due to chlorophyl. No chromatophores can be distinguished. Mount some spores in alcohol, stain with hæmatoxylin, and try to make out a nucleus. Treat another mount of the spores with Schultze's solution, and describe the effects on the cell wall, nucleus, and cell contents. Treat another mount with caustic potash and describe the effects.

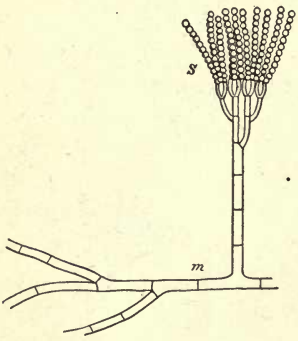

FIG. 87. — *Penicillium glaucum.* *m*, a portion of the mycelium; *s*, gonidiophore showing the chains of spores. (Vines.)

5. Make hanging drop cultures of the spores. Set aside in warm places and examine from day to day to watch the development of the spores. Make drawings, showing the development of successive stages.

6. Mount a little of the mycelium in 30 per cent alcohol, tearing it apart with needles. Notice the granular protoplasm. Do you find vacuoles? Treat with Schultze's solution. Of what kind of cellulose is the cell wall composed? Mount some more of the mycelium in alcohol, stain with hæmatoxylin, and make out the nuclei.

Show by a figure the manner in which the mycelium branches. Are the branches of uniform diameter? If not, state what differences you notice; examine the ends of the hyphæ particularly. Treat another mount with one per cent solution of osmic acid. A brown coloration shows the presence of oil. This oil is one of the products of the destructive metabolism of the protoplasm.

References for Reading. — Parker's "Elementary Biology," pp. 184–191; Bidgood's "Elementary Biology," pp. 80–84; Dodge's "Practical Biology," pp. 297–300; Huxley and Martin's "Practical Biology," pp. 415–426; Strasburger and Hillhouse's "Practical Botany," pp. 259–261.

EUROTIUM. — PRACTICAL STUDIES.

Eurotium first appears as a white, cottonlike growth; later yellow spots develop. It grows so readily on poorly dried plant specimens that it receives the name *Herbarium Mold*. It is also found on old leather, boot blacking, and various other substances.

1. Mount a little Eurotium in water and examine the mycelium under high power. Notice the septa. Draw a typical case of branching. Run Schultze's solution under the cover glass. Is the cell wall composed of normal or of fungous cellulose?

2. Study the asexual reproduction. Are the gonidiophores branched or unbranched? Are they divided by septa? Describe the manner in which the gonidia are borne. Draw a gonidiophore to which a considerable number of gonidia are still attached.

Make hanging drop cultures of the spores. Make drawings on at least four different days, showing the progress of the growth.

3. Study the sexual reproduction. Material for this study is to be obtained from Eurotium that has been growing for some time. It may be recognized as suitable by

the yellow color distinctly visible to the naked eye. Draw a typical spore fruit. By pressure on the cover glass burst some of the spore fruits and study the ascospores. Eight ascospores are borne in each sac. Find as many as possible of the stages in the development of the spore fruit. The beginning of the development is by the outgrowth of a spirally coiled branch which becomes the ascogonium. From just beneath this another branch, the *pollinodium*, rises, extending to the top of the ascogonium. It is supposed, though this fact has not been proved, that the pollinodium fertilizes the ascogonium. The ascogonium becomes enveloped in other branches which start from below its base and tightly inclose it. The mature ascogonium bears several sacs, each containing eight ascospores.

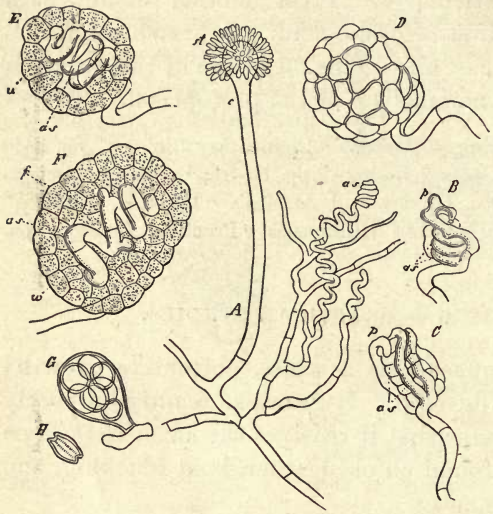

FIG. 88. — *Eurotium repens*. *A*, a portion of the mycelium bearing at *st* a gonidiophore, and at *as* a young ascogonium; *B* and *C* show the ascogonium more advanced and enveloped in the pollinodium *p*; *D* is a fully matured ascogonium; *E* and *F* are sections through a young ascogonium; *G* is one of the asci or sacs that are borne in the ascogonium, and *H* is one of the ascospores which are borne in the ascus. (After Goebel.) See Fig. 86, 4 and 5.

References for Reading. — Bennett and Murray's "Cryptogamic Botany," pp. 364–366; Huxley and Martin's "Practical Biology," pp. 419–427; Bower's "Practical Botany," pp. 484–490; Goebel's "Classification of Plants," pp. 105–107.

CLASS V.—**The Rusts** (*Æcidiomycetes* or *Uredineæ*).—The Rusts are parasites which infest the tissues of higher land plants. They sometimes grow in the intercellular spaces, and perhaps do no injury to their host. In other cases they grow in the cellular tissues, often causing great deformity and injury. (See Fig. 89.) The spores are produced beneath the epidermis of the host. They are somewhat of the color of iron rust, and so give the common name to the plant. Many species of Rusts produce different kinds of spores, but not on the same plant. There is a succession in their development which requires plants of different kinds. A familiar example of this is the Rust that causes disease in Wheat. It is known as *Puccinia graminis*. It has different kinds of spores. One kind grows on the Wheat; the other kind on Barberry bushes. In the spring cuplike yellow clusters develop on the Barberry leaves, producing spores called *æcidiospores*. These spores are carried by the wind to Wheat fields, where they grow and produce an entirely different kind of spore, called *uredospores*. These new spores are carried to other Wheat plants and develop. This continues as long as the conditions are favorable. Late in autumn spores with thick coats are produced, called *teleutospores*. These develop in the spring on Barberry leaves into cuplike clusters which bear the æcidiospores.[1]

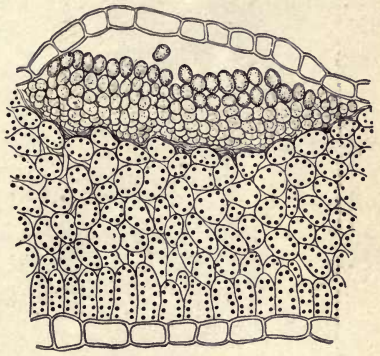

FIG. 89.—Section of Blackberry leaf, showing development of Orange rust spores. (After Clinton.)

[1] Have on hand material collected from the different sources mentioned and at the different seasons, and arrange Practical Studies.

Another species of Rust, *Puccinia rubigo-vera*, affects Wheat in the United States. This has no connection

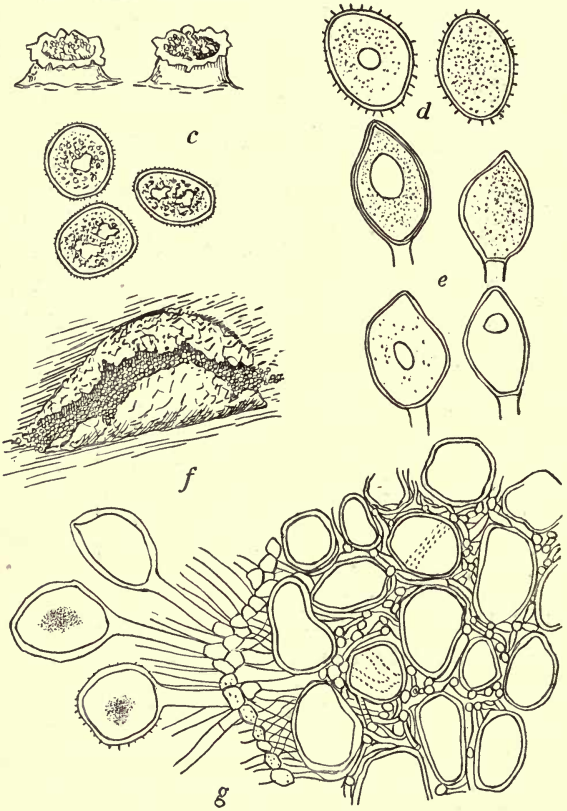

FIG. 90. — Clover Rust. *c*, cluster cups and æcidiospores; *d*, uredospores; *f*, uredo pustule on Clover leaf; *e*, teleutospores; *g*, cross section of Clover stem, showing mycelium between cells; also two teleutospores and one uredospore. (After Pammel.)

with the Barberry, but its different stages are passed on the Wheat and on plants of the Borage family.

The abnormal growth on the twigs of Cedar, known as *cedar apples*, affords opportunity for the study of an-

other interesting Rust. These cedar apples, if examined in autumn or winter, are seen to be covered with elevations under the bark. They are now in good condition for study. Thin sections show the spores in their sacs. The bark over the elevations breaks away in the spring and the rust-colored spores appear on the surface. These spores are the teleutospores. They will not grow on the Cedar, but if, borne by the wind, they fall on the leaves of the Apple or Hawthorn, they grow and produce another kind of spore — the kind that flourishes on Cedar.

FIG. 91. — Cedar apples (*Gymnosporangium clavipes*). (Farlow.)

The shape of the teleutospores determines the classification of the Rusts ; in all other stages the different kinds of Rusts resemble one another so much that they cannot be distinguished.

No sexual reproduction is known, though it is supposed that it does exist.

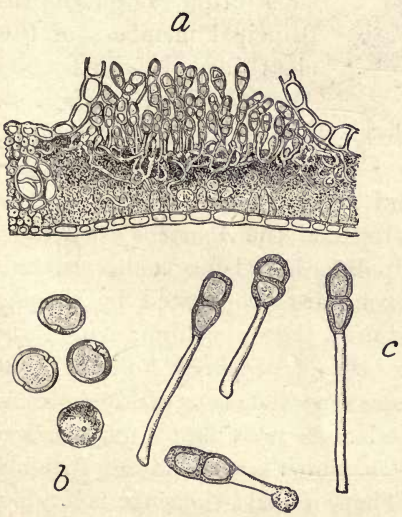

FIG. 92. — Corn Rust, *Puccinia maidis*. *a*, section of leaf, showing teleutospores; *b*, uredospores; *c*, teleutospores. (Clinton.)

References for Reading. — Goebel's "Classification of Plants," pp. 126–131;

Carpenter's "The Microscope," pp. 565, 566; Vines' "Text-Book of Botany," pp. 303–308; Bennett and Murray's "Cryptogamic Botany," pp. 383–386; Cooke's "Introduction to the Study of Fungi," pp. 242–250.

CLASS VI. **The Toadstools and their Allies** (*Basidiomycetes*). — This is a large class and contains a great variety of forms, including some of the largest and handsomest of the Fungi. They are for the most part saprophytes; a few are parasites. The portion of the plant that appears above the ground or other substratum on which it grows is the fructification. The plant itself consists of delicate white threads, the *mycelium*, which ramify through the substratum. Popularly the principal members of this class are divided into *Toadstools* and *Mushrooms*. Under the latter name are included those forms that may be used as food, and more particularly the species that is largely cultivated for food, the *Agaricus campestris*. From the botanical standpoint, there is no such classification. The cultivated forms are propagated by placing masses of humus containing the mycelium, which the gardener calls *spawn*, in beds of prepared humus. The mycelium spreads and bears repeated crops of Mushrooms. The fructification of Toadstools is at first a more or less egg-shaped body, the *button*, which is some days in forming under the substratum. Then, if conditions are favorable, it shoots up very quickly into the fully formed Toadstool.

FIG. 93. — A typical gill-bearing Toadstool. (Weed.)

A large number of Toadstools are edible, and many of

them are said to be most delicious and nutritious articles of food. Directions are given in the books for distinguishing the edible forms from those that are not edible. As a matter of fact, however, there are deadly poisonous forms which so closely resemble nearly all the edible forms that even the expert acknowledges the impossibility of describing so that one unfamiliar with them may be at all sure of distinguishing the edible from the poisonous. The only safe rule for the novice is not to eat Mushrooms, unless under the guidance of some one who has had experience.

All the more important species of Toadstools may be brought under the following classification:

A. THE HYMENOMYCETES, bearing exposed spores.
- I. *The Agaricineæ*, or Gill-bearing Toadstools.
- II. *The Polyporieæ*, or Tube-bearing Toadstools.
- III. *The Hydneæ*, or Tooth-bearing Toadstools.
- IV. *The Clavarieæ*, or Coral-shaped Toadstools.

B. THE GASTEROMYCETES, bearing internal spores.
- V. *The Puff Balls.*

I. **The Gill-bearing Toadstools** (*Agaricineæ*). — By far the largest number of Toadstools are included among the Agaricineæ. They are distinguished at once from members of the other divisions by the *gills*, or *lamellæ*, situated on the under side of the *pileus*, or umbrella-shaped top.

THE GILL-BEARING TOADSTOOLS. — PRACTICAL STUDIES.

1. Obtain a number of different kinds of gill-bearing Toadstools. In collecting, dig well into the ground, and secure the entire fructification, together with some of the mycelium. Compare the specimens as to height of the stipe, or supporting stalk, and the shape, diameter, and color of the pileus.

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Find forms that have an *annulus*, or ring, on the stipe, a short distance below the pileus. This is the remnant of the *velum*, or veil, which in the button stage enveloped the whole fructification. As the button developed into the full-sized Toadstool, the velum parted. Find remains of it around the edge of the pileus. In some cases the annulus is a true ring, and is movable up and down on the stipe; in other cases it is firmly attached to the stipe and persists; in others it disappears.

Find forms having a *volva*, or envelope, at the base, extending a short distance up the stipe. Toadstools having a volva are to be avoided as poisonous. Draw specimens, showing all the points mentioned. (See Fig. 94.)

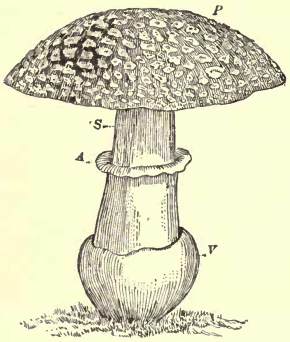

FIG. 94. — *Amanita rubescens*. *S*, stipe; *P*, pileus; *A*, annulus; *V*, volva. (After Le Maout and Decaisne.)

2. Allow a number of different kinds of Toadstools to decay. Notice that some shrivel up or decay in the ordinary way, and others turn wholly into a dark, inklike fluid.

3. Look for Toadstools growing in the woods. Dig up some with considerable earth clinging to the bases. Carefully pick this away and notice the thread-like root portions. These threads are the real plant. They constitute the mycelium. Examine some of the threads under the microscope.

4. Compare the gills of the different species. In some they extend from the edge of the pileus to the stipe. In others some of the gills extend the entire distance from the edge of the pileus to the stipe, and some extend only part way. In some the gills do not quite reach the stipe. In others they extend part way down on the stipe. In

some the gills are thin and sharp. In others they are thick and blunt. Draw each different type found, showing view of pileus from below. Notice and describe the color of the gills in each different specimen.

5. Cutting the stipes close to the pileus, allow different kinds of well-matured Toadstools to rest, gills downward, for some time on sheets of paper. The spores will fall out in abundance. Compare them as to color. The cultivated Mushroom, *Agaricus campestris*, has dark purple spores. Forms with white or light-colored spores are in most cases poisonous. Examine the different kinds of spores under high power.

6. Cut the stipes of different specimens transversely. Notice and record whether the stipe is solid or hollow; whether it turns dark after being cut; whether a juice exudes, and, if one does, what its color is. Forms having a juice, except those having a red juice, are believed to be poisonous.

7. Cut vertically through a specimen that has both volva and annulus so as to show a section through the entire Toadstool from the base of the stipe to the top of the pileus. Draw.

8. Make longitudinal microscopic sections of the stipe. For this purpose the material must be hardened by treating pieces not more than half an inch square and quarter of an inch thick with chromic acid for about 24 hours; wash out the acid in water and keep the specimens a day successively in 50, 75, and 90 per cent alcohol. Hold the specimen between two pieces of pith when cutting sections. Examine the sections in dilute glycerine under both low and high powers, and determine that they are made up of interwoven filaments or hyphæ. Treat a section with Schultze's solution, which stains normal cellulose blue or violet, and fungous cellulose brown. Is it composed of normal or fungous cellulose?

9. Make sections of the pileus so as to obtain transverse vertical sections of the lamellæ. A Toadstool just ready to open should be used. Examine a lamella under high power. The central portion is the *trama;* compare its structure with the structure of the stipe. Outside of the trama are the *subhymenium* and the *hymenium.* Projecting from the hymenium are the *basidia*, large cells having pointed extensions on the outer ends. In some cases the spores will be found still attached to these points; in other cases they will have fallen off. What is the shape of the spores? These spores are sometimes called *basidiospores*, from the manner in which they are borne. They are of the type known as *gonidia.* Between the basidia notice the projecting cells with round ends; these are *paraphyses.* Draw a portion of the lamella, showing all the parts seen. (See Fig. 95.)

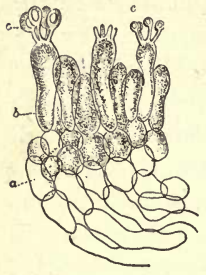

FIG. 95. — A portion of one of the gills showing the manner in which the spores are borne. *a* and the cells below it are cells of the trama; *b* is a basidium; *c*, spores; the cells projecting upward between the basidia are paraphyses. (After Brefeld.)

II. **The Tube-bearing Toadstools** (*Polyporieæ*). — The members of this group are also easily recognized. They have the general umbrella shape of the gill-bearing forms, but in place of the gills are numerous tubes arranged vertically and parallel to one another. The commonest forms belong to the genus *Boletus.* This genus includes many poisonous species and a few highly prized edible species.

THE TUBE-BEARING TOADSTOOLS. — PRACTICAL STUDIES.

1. Collect as many different kinds of tube-bearing Toadstools as you can find. Compare them as to color, shape, and size of the pileus. Do you find any forms with an annulus? Any with a volva?

2. Cut through the stipes transversely. Are the stipes solid or hollow? If you find any that have juices, state the color of the juices. Do the stipes darken after being cut?

3. Cut through an entire Toadstool from the base of the stipe to the top of the pileus. Draw.

4. Obtain spores by allowing some of the Toadstools to remain tube-bearing side down on a sheet of paper. Compare the colors of the spores. Examine them under high powers.

5. Harden pieces of the tube-bearing portions in chromic acid and make microscopic sections transversely through the tubes. Under high power examine the inner edges of the tubes for the hymenial layer, basidia, paraphyses, and spores.

III. **The Tooth-bearing Toadstools** (*Hydneæ*). — These have the umbrella shape of the two preceding groups, but in place of the gills, or tubes, toothlike points extending downward beneath the pileus. They are not very abundant. They are said to be nonpoisonous, but are not much sought after for food, with the exception of one or two species, on account of their disagreeable bitter taste.

IV. **The Coral-shaped Toadstools** (*Clavarieæ*). — These are readily recognized from their shape. They are not abundant. They are not poisonous, and are esteemed as food.

V. **The Puff Balls.** — These constitute only one of the groups of the Gasteromycetes. They are closely related to the Toadstools, though they present marked points of difference. They are produced by a subterranean mycelium which decays from the base of the fructification as it matures, and leaves the latter as a loose ball on the surface of the ground. This ball is wholly inclosed. The interior is at first white, but as it matures becomes one mass of black spores. The Puff Balls are not poisonous,

with the possible exception of one common species, and are eaten when young and before the spores have begun to turn dark.

References for Reading. — Goebel's "Classification of Plants," pp. 131–139; Vines' "Text-Book of Botany," pp. 310–320; Bennett and Murray's "Cryptogamic Botany," pp. 388–399; Parker's "Elementary Biology," pp. 191–193; Bower's "Practical Botany," pp. 453–461; Dodge's "Practical Biology," pp. 301–307; Carpenter's "The Microscope," pp. 575, 576; Gibson's "Our Edible Toadstools and Mushrooms"; article by Gibson on Edible Mushrooms, in *Harper's Magazine* for August, 1894; Cooke's "Introduction to the Study of Fungi," pp. 119–163; Farlow's "Notes for Mushroom Eaters"; Palmer's "About Mushrooms."

VI.

THE BRYOPHYTES.

A higher differentiation of root, stem, and leaf distinguishes the Moss plants from plants of the preceding subdivisions. There is a distinct alternation of generations from the gametophyte, the ordinary Moss plant, to the sporophyte, which develops in the archegonium on the female gametophyte and there produces spores. The differentiation into stem and leaf is outwardly quite well marked, but the inner structure shows only slight progress in these directions. Roots are represented by unicellular or multicellular filaments called *rhizoids*. The stem shows a decided tendency to the formation of fibrovascular bundles. Gonidia are not formed, but *gemmæ* reproduce some of the plants of this subdivision vegetatively. There are no saprophytes or parasites. All the Bryophytes are chlorophyl-bearing plants of holophytic nutrition. Much moisture is necessary to their vigorous life; hence they are found in shady damp places on the ground, on the lower parts of the trunks of trees, and on rocks. There are two classes.

CLASS I. THE LIVERWORTS (*Hepaticæ*).
CLASS II. THE MOSSES (*Musci*).

CLASS I. **The Liverworts.** — The Liverworts are for the most part low, flat, thalloid plants. They grow in moist locations on the earth and on the rocks along streams and ditches, and in great abundance on the soil in damp greenhouses. The common Liverwort, *Marchantia poly-*

morpha, is one of the largest of the class and is well suited for study.

There are two modes of asexual reproduction. By one, buds or gemmæ are formed in little cups or cupules which grow on the upper surface of the frond; these, when ripe, fall out and are scattered over the ground, where they take root and produce new plants. By the other mode new and separate plants result from the dying away of the oldest portions of the frond. The frond branches dichotomously; as the older part dies, the branches become separated, and each continues its existence as a new plant. Reproduction by this mode is said to be by *innovation*.

FIG. 96. — A mass of *Marchantia polymorpha* bearing the male inflorescence. (After Bennett and Murray.)

There is considerable variation in the different orders of Liverworts in the positions of the organs of reproduction. In some orders both the male and female inflorescences are borne on the same plant; that is, the Liverwort is monœcious. In other orders the plant is diœcious. In the common Liverwort the male inflorescence is borne on umbrella-shaped branches. The branches rise an inch or more from

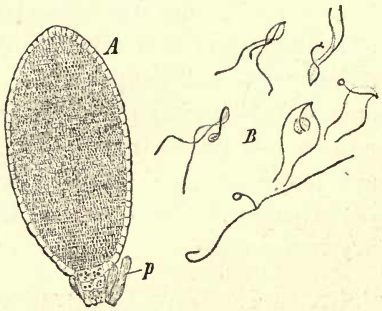

FIG. 97. — An antheridium of *Marchantia polymorpha*. The antheridia are borne on the upper surface of the umbrella-shaped branches seen in Fig. 96. *B* are antherozoids that have been set free. (After Goebel.)

the frond, and the antheridia grow from the upper surface of the scalloped-edged circular top. The antheridia are modified hairs. The female inflorescence is borne on branches of other plants of about the same height as the male branches. The tops differ in that the lobes are slender and are cut well in toward the center. The top has been compared to a wheel without the rim. The archegonia are borne on the under side, concealed in tissues in the grooves of the rays. These are also modified hairs. (See Figs. 96, 98, and 99.)

The antherozoids, borne in the antheridia, swim out when there is moisture on the plant — drops of dew are sufficient — and find their way to the archegonia. Passing down through the neck, they come in contact with the egg cells, which they fertilize. A spore fruit results, and the spores develop by fission of cells into small and simple growths called *protonemæ*, from which new plants arise. (Figs. 97 and 101.)

COMMON LIVERWORT.[1] — PRACTICAL STUDIES.

1. Examine with the naked eye a considerable number of specimens of Liverwort. It is not possible to find all the different stages of development at some seasons of the year, and alcoholic material must then be used in part of the work. Find, if possible, plants bearing cupules, some bearing the male inflorescence, and some bearing the female inflorescence. Notice how the plants branch. Examine the end of each branch. What do you observe? Do the two parts which result from a given division develop into branches of equal size? Do you find a midrib? If so, can you trace it along the main stem of the thallus and along the branches? Measure and state the length and breadth of several plants. Observe the color. Are all

[1] Similar Practical Studies may be made of any other species of Liverwort.

parts of the same color? Carefully remove some of the plants from the earth on which they grew and wash off the dirt. Compare the proximal and distal ends. Do you find that the stem rises as the continuation of a true root? Notice the numerous hairy rhizoids. What color

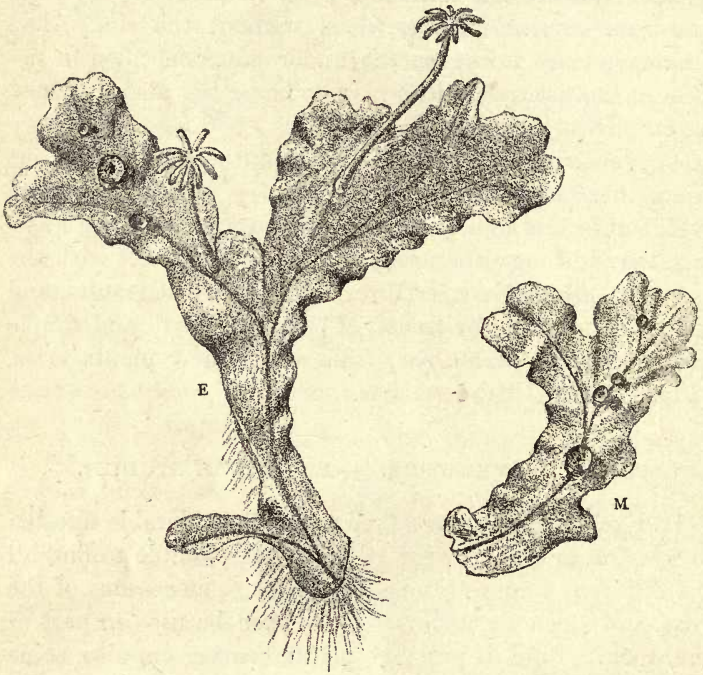

FIG. 98. — Portions of plants of *Marchantia polymorpha* showing the dichotomous division. *E* shows two cases of the female inflorescence, cupules on the left-hand branch, and rhizoids at the base; *M* bears cupules.

are they? Where are they situated? Observe the cupules on some of the plants. What is their shape? Are they sessile or raised on stalks? Notice in them the little buds or gemmæ. Draw specimens, showing as many of the points observed as you can.

Examine plants bearing male or antheridial branches.

Where on the thallus are the male branches borne? Measure and state the length of the pedicel, or stalk, in several specimens; also the diameter of the head, or receptacle. Draw a receptacle seen directly from above, showing the exact number of lobes. Notice grooves on the pedicel. How many are there and where are they situated?

Examine plants bearing the female or archegonial branches. Where on the thallus are the female branches borne? What is the greatest length of pedicel that you find? Do you find grooves on the pedicel? If so, what is their number and where are they situated? Draw a receptacle seen from above, showing the number of lobes. Also draw plants, showing the male and female inflorescence.

2. With a magnifying glass examine the upper surface of a thallus for rhomboidal areas or areolæ. Observe that there is a small opening in the center of each areola. This is a stoma, or breathing pore, and is the first instance thus far met of the occurrence of an organ that is common to all the higher plants. Do you find areolæ and stomata on the under surface of the thallus? Among the rhizoids find purple and colorless scales. On what parts of the thallus do you find each? Draw some of the scales and hairs.

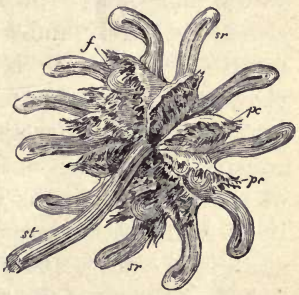

FIG. 99. — A female inflorescence of *Marchantia polymorpha*. The archegonia are borne among the hairs on the under surface, which is presented to view in the figure. (After Goebel.)

3. Study the structure of the thallus, using first low, then high power. Strip off some of the epidermis of the upper surface and examine the areolæ, epidermal cells, and stomata. Draw a stoma as seen under high power, showing the number and arrangement of the exterior

supplementary guard cells and some of the surrounding epidermal cells. Focus down and notice the number, shape, and arrangement of the true guard cells. Draw. In a similar way study the epidermis of the lower surface of the thallus. Draw a few of the epidermal cells, selecting some that show how a hair originates. Do you find stomata? Remove some of the hairs and study them under high power. Find two kinds, — the fine silky rhizoids, situated directly under the midrib, and coarser hairs, showing projections extending inwards from a spiral constriction. The outline of the coarser hairs as seen in optical section appears scalloped. (Fig. 102.)

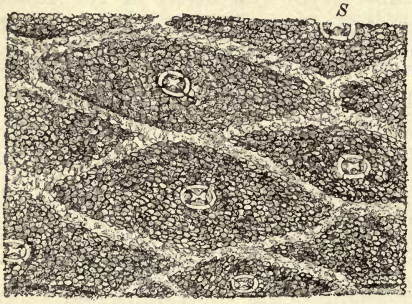

FIG. 99*a*. — A portion of the epidermis of the upper side of *Marchantia polymorpha*, showing areolæ and stomata. (× 480.)

Imbed a piece of the thallus in pith and cut transverse sections. Mount some in water and some in alcohol. Draw an entire section and indicate each of the following parts on it. Notice the row of colorless cells of the upper epidermis. Hunt along this row for a section through a stoma. If one is found, draw it. Below

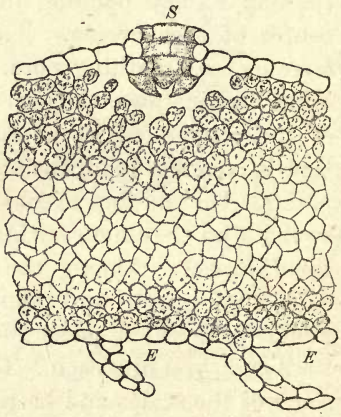

FIG. 100. — A vertical section through a plant of *Marchantia polymorpha*, showing a stoma at *S*, the air cavity below it, and scales at *EE*.

the epidermal cells, notice the rows of green parenchyma containing numerous chlorophyl bodies. Determine if starch is present. In the green parenchyma, find air cavities lined with bright green cells. A stoma connects each air cavity with the outer air, but may not lie in the plane of the section. Below the green parenchyma, notice colorless parenchyma extending to the epidermis of the lower side of the thallus. Can you find hairs and scales growing from the lower epidermis? If so, draw them.

4. With a razor cut off two cupules. Mount one face up, the other face down, in water, pressing on the cover glass to flatten them down. Notice on the first, under low power, a fringe of teeth; then examine one of the teeth under high power. What is its shape? Do you find any hairs? Using the second specimen, examine the lower surface of the mount for hairs.

Imbed in pith a piece of the thallus bearing cupules and make sections passing vertically through a cupule. Draw the sections under the low power. Examine under low power for gemmæ. Under high power, trace the development of the gemmæ. They should be found in all stages of growth.

Examine mature gemmæ under both low and high powers. Make out the scar which shows where the gemma was attached to its stalk; also the two vegetative notches half way up the sides. Draw a gemma. Study also gemmæ that have begun to germinate. Gemmæ that have been in water for a number of days should be used. Compare with the gemmæ that have not germinated. Draw. Sow some gemmæ on sand in a moist chamber. Keep in the sunlight. They will sprout in a few days. Watch their development until the characteristic structures of the Liverwort are apparent; make drawings at intervals.

5. Study the structure of the antheridial branch. Ex-

amine the pedicel with a magnifying glass and notice the rhizoids and leaf scales along the grooves. Examine a cross section of the pedicel under low power. Draw. Examine the same section under high power, noticing particularly the rhizoids and leaf scales as seen in section.

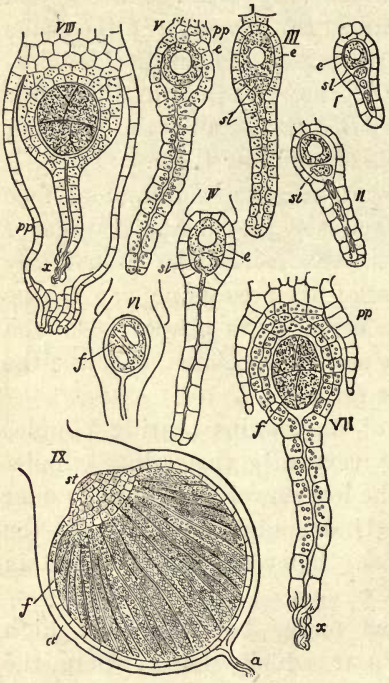

FIG. 101. — The archegonium of *Marchantia polymorpha* in different stages of its growth. *I–V* show it before fertilization. The antherozoids, which are produced in the antheridia, and which are shown in Fig. 97, enter at *x*, pass up through the long neck, and fertilize the oösphere. A sporogonium results. This is seen in different stages in *VII* and *VIII*, which also show the shriveling of the cells of the neck that occurs after fertilization. *IX* shows a developing sporogonium filled with spores and elaters; *a* is the neck of the archegonium wholly withered up. (After Goebel.)

With a magnifying glass observe the antheridia on the upper surface of the receptacle. Imbed in pith and make vertical sections through the central part of the receptacle. Under high power find the antheridia in their somewhat ovoidal cavities. Draw. Near the antheridia one celled, hairlike paraphyses may be found in specimens that are not too mature. In the case of mature antheridia, antherozoids may be seen in the cells or swimming in the water. This observation is difficult; the antherozoids may, perhaps, be obtained by placing a drop of water on the top of an antheridium, the upper part of which has been kept

free from wetting for several days; after a few minutes transfer the drop of water to a slide by inverting the antheridium on the slide. It is to be remembered that motile antherozoids can be found only at the seasons of the year when the plants are at the right degree of maturity.

Compare the upper and lower surfaces of the male receptacle with the corresponding surfaces of the thallus.

6. Study the structure of the archegonial branch. With a magnifying glass examine the grooves on the under side of the receptacle. Imbed a receptacle in pith, make vertical sections, and examine with high power for archegonia. These are shaped something like a flask with a long neck. The archegonia may also be obtained for examination by scraping out the contents of one of the grooves into a drop of water. Draw an archegonium, showing clearly its stalk, body, and neck. Try to make out the internal structure of an archegonium, studying as many specimens of different stages of development as can be found. Crush under the cover glass some of the fully matured archegonia; study the spores and elaters. The latter are marked by delicate spiral bands. Draw both. Crush a ripe archegonium on a glass slip without moisture. Examine under high power, and while looking through the microscope let some one breathe gently on the mass. What happens to the elaters? What mechani-

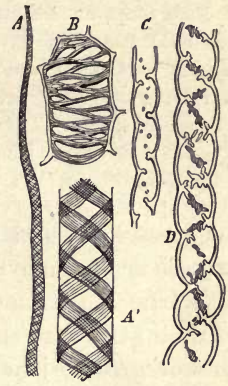

FIG. 102. — Cells from *Marchantia polymorpha*. *A*, an elater; *A'*, part of same, showing spiral cell walls; *B*, a cell from the plant body showing pitted markings of the cell wall. This is the first instance in ascending the scale of plant life of a structure very common in the higher plants; *C* and *D*, rhizoids, such as are seen at the base of *E*, Fig. 98. (After Sachs.)

cal purpose may the elaters serve in the distribution of the spores?

References for Reading. — Goebel's "Classification of Plants," pp. 140–163; Vines' "Text-Book of Botany," pp. 324–354; Bennett and Murray's "Cryptogamic Botany," pp. 132–136, 156–171; Strasburger and Hillhouse's "Practical Botany," pp. 194–196, 272–277; Bower's "Practical Botany," pp. 360–378; Dodge's "Practical Biology," pp. 308–319; Boyer's "Elementary Biology," pp. 134–139; Carpenter's "The Microscope," pp. 590–594.

CLASS II. **The Mosses.** — The Lichens, Liverworts, and Mosses are popularly but incorrectly spoken of as Mosses. The true Mosses are distinctly higher in the complexity of their structure than the Lichens and Liverworts. The axis of growth is more erect; the plant is provided with truer leaves, with rhizoids that closely approach true roots in character, and shows a greater differentiation in the tissues of the stem. The cells on the outside of the stem are elongated, are of a red-brown color, are thick walled, and approach the structure of bark more nearly than any tissues hitherto studied, though the epidermis is very imperfectly developed. Again the cells in the center of the stem are thin walled, and are aggregated into a distinct axial bundle, which simulates in function, and to some extent in structure, the fibrovascular bundles of all the higher plants. The growth of the stem is by the division of an apical cell which grows concealed in the leaves. This cell has the shape of a triangular pyramid with the apex pointing down. In dividing, a slice splits off from one of the sides of the pyramid; then a slice splits off from a second side; then one from the third side, the pyramid growing to its original size before each fission. Each of the slices divides into many cells, which develop into the tissues of the stem, leaves, and rhizoids.

Mosses are reproduced asexually by different modes of budding, but not, so far as is known, by asexual spores.

In the sexual reproduction Mosses are either monœcious or diœcious. Antherozoids swim to and fertilize the egg cells produced in archegonia growing on the same or on another plant. The result of this fertilization is the sporophyte form of the plant, which develops *in situ* in the archegonium. The capsules containing the egg cells become filled with spores that closely resemble the asexual spores of some other plants. The spore, in germinating, produces a branching filament known as a *protonema*, which gives off lateral buds from which new Moss plants grow.

POLYTRICHUM COMMUNE.[1] — PRACTICAL STUDIES.

Polytrichum commune, or Hairy-cap Moss, is one of the largest and most common of the Mosses. It grows in abundance in dark green patches in the woods, fields, and along the road sides. The plants are from three to six inches tall. The stems are usually simple, but sometimes are forked. The leaves are from half to two thirds of an inch long. (See Fig. 103.)

1. With the naked eye examine some plants of *Polytrichum commune*. Find male or antheridial plants, recognized by a starlike cluster at the top. (Fig. 103, *M.*) These clusters develop in the spring, but remain conspicuous throughout the season. Some male branches show two or more clusters. After the formation of the lower cluster, the apical bud continued to develop and formed other clusters. This is known as *prolification*. Find an instance of it. (See Fig. 103, *P.*)

Find a female or archegonial branch. In the spring the archegonium is concealed among the leaves of a stem that is more pointed than the male stem. After fertilization the female stem sends up a long, slender red shoot, or

[1] Similar Practical Studies might be made of any other Moss, as Sphagnum, Mnium, Bryum, Atrichum, or Bartramia.

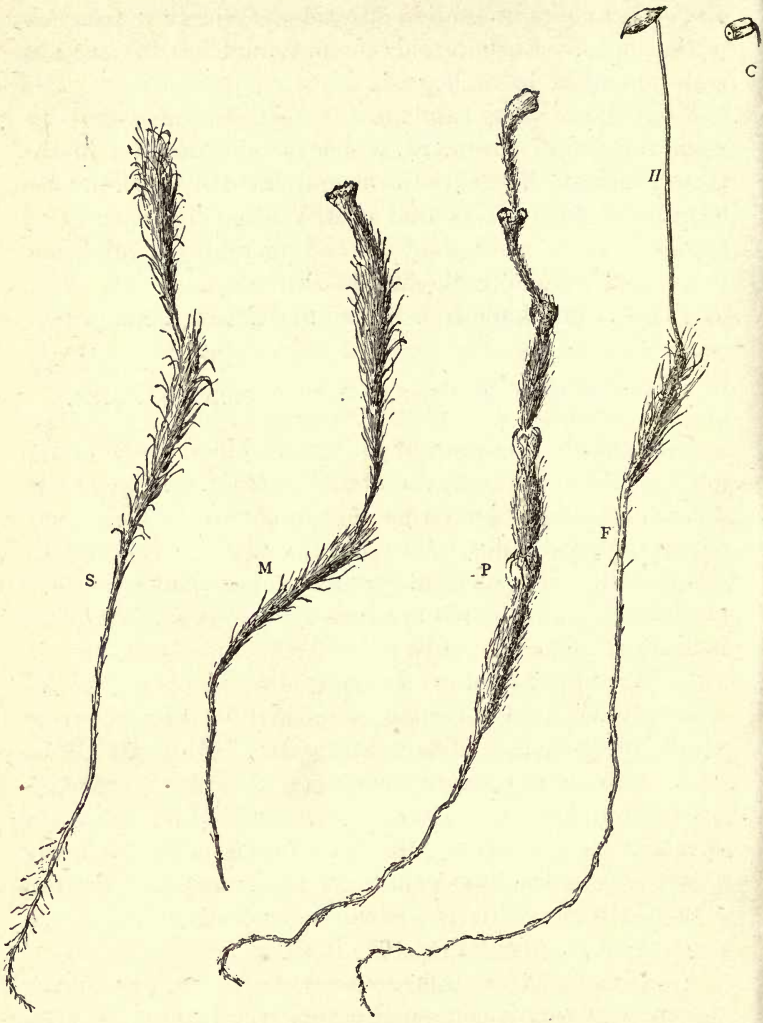

FIG. 103. — *Polytrichum commune.* *S*, sterile plant; *M* and *P*, male plants; *F*, female plant; *H*, seta; *C*, sporangium; *P* shows prolification.

seta, which bears at its top a capsule. (See Fig. 103, *F*.) A *calyptra*, or cap, with pointed apex, envelops the capsule with long silky hairs.

Find also sterile branches. These are recognized by their pointed tops and the lack of the characteristics already described for the male and the female branches. Note the position and arrangements of the leaves and rhizoids on each of the three kinds of branches. Draw each.

2. Imbed in pith, celloidin, or paraffin, pieces of the root end of the stem and cut cross sections. Study the structure under both low and high power. Notice the imperfectly differentiated epidermis, the cells with thickened wall next within the epidermis, and the somewhat distinct bundle of thin-walled cells, the axial bundle, in the center. (See Fig. 104.) Describe the rhizoids as seen on the section. Draw the entire section. Run Schultze's solution under the cover glass. This solution stains lignified cellulose yellow. Do you find both normal cellulose and lignified cellular tissue?

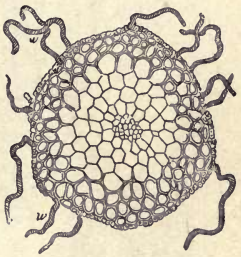

FIG. 104. — Cross section of the stem of the Moss, *Bryum roseum*, showing a simple differentiation of the tissues at the center to form a fibrovascular bundle. The imperfect development of the bark and the appearance of the rhizoids are also shown. (After Goebel.)

Mount some of the rhizoids in water and examine under low power. State how the cells are arranged. Do the rhizoids branch? Draw a rhizoid.

3. Examine a leaf under low power. Draw the entire leaf. Do you find a midrib? Notice the teeth or spines on the margin — forms of plant hairs. Under the high power draw one of the teeth and a few of the adjacent cells. If dried material is used, the leaves should be soaked in dilute caustic potash for twenty-four hours previous to this observation to render them transparent.

Boiling the leaves in Schultze's macerating mixture serves the same purpose. Also draw, under high power, a few cells from the wide base portion of the leaf. Have you found stomata? Examine pieces of the epidermis torn from the stem for stomata. Do you find them? Stomata are sometimes found on the midribs of the leaves and on the setæ.

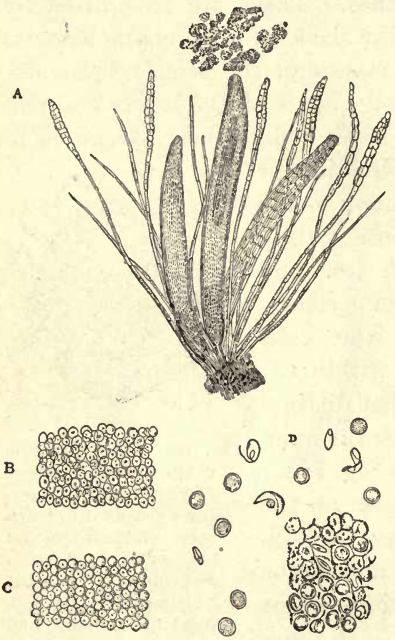

FIG. 105.—*A*, antheridia and filiform and spatulate paraphyses of *Polytrichum commune*; *B*, *C*, and *D*, antherozoids of same in their cysts, and variously magnified. (After Thuret.)

Under low power draw one of the leaves or bracts from an antheridial head. Draw a few cells of the bract as seen under high power.

Examine under low power cross sections of the leaf. The sections are best cut from pieces of the upper, leafy portion of the stem imbedded in celloidin. Some of the sections of the leaves will be nearly or quite transverse. Locate the axial bundle of the midrib. Notice the lamellæ on the upper surface. Draw the entire section. Also draw some of the lamellæ as seen under high power.

4. If material gathered in the spring can be studied, dissect a male head in water and try to make out, using both low and high powers, the antheridia — somewhat thick, ovoidal bodies made up of polygonal cells — and

filiform and spatulate paraphyses. Draw. If fresh material is employed, crush the antheridia by pressure on the cover glass, and try to see the flagellated antherozoids. This is difficult. The antheridia and paraphyses may also be studied in vertical sections cut from a male head imbedded in celloidin. (See Figs. 105, 106, 107.)

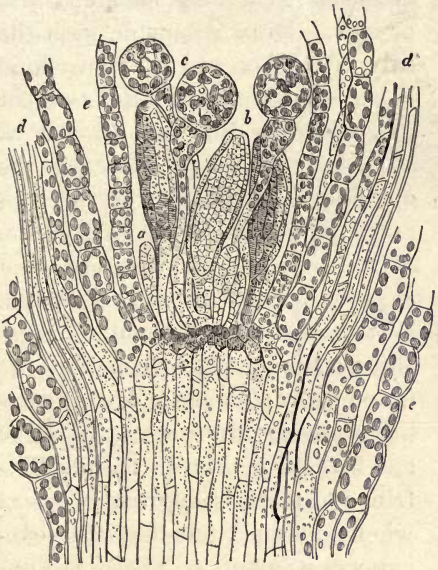

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FIG. 106. — Vertical section through the top of a male plant of *Funaria hygrometrica*, showing how the antheridia are borne. *a* is a young antheridium; *b* is a more mature antheridium seen in section; paraphyses are seen at *c*. (After Goebel.)

FIG. 107. — An antheridium of the Moss, *Funaria hygrometrica*, allowing the antherozoids to escape. At *b* is an antherozoid in its cyst; at *c* the antherozoid has been wholly set free. (After Goebel.)

5. Study the female head in material collected in the spring; fresh material is to be preferred. Tease out a head in a drop of water and find flask-shaped archegonia with short foot stalks and long, slightly curved necks. Draw. Focus into the neck and make out the canal

FIG. 108. — *A* is a vertical section through the top of a female plant of *Funaria hygrometrica*, showing how the archegonia are borne; *B* is an archegonium more highly magnified. The antherozoids seen in Fig. 107 pass down through the neck, *m*, and fertilize the egg cell, which is seen centrally located at *b*; *C* is the neck of the archegonium more highly magnified. (After Goebel.)

leading from its top down to the oösphere or egg cell in the central portion of the archegonium. (See Fig. 108.)

6. Study the matured fruit. After the oösphere is fertilized, it is raised on a long, slender stalk, or seta. Draw a capsule with the calyptra still on and one from which it has been removed. Remove the *operculum*, or lid, and draw it as seen from above. Beneath the operculum the mouth of the sporangium, or urn, is covered with a delicate diaphragm surrounded by a peristome or fringe of teeth. With a razor cut off the diaphragm and peristome, place them top side up on a dry slide, and, while examining under low power, let some one breathe gently on them. The fringe of teeth is hygrometric, *i.e.*, when moisture touches it, it executes movements. These motions are believed to be a means for scattering the spores from the urn. Examine some of the spores.

References for Reading. — Parker's "Elementary Biology," pp. 332–343; Goebel's "Classification of Plants," pp. 163–188; Vines' "Text-Book of Botany," pp. 354–371; Carpenter's "The Microscope," pp. 594–599; Strasburger and Hillhouse's "Practical Botany," pp. 190–195, 277–286; Bower's "Practical Botany," pp. 341–359; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 84–102; Lesquereux and James' "Mosses of North America"; Strasburger, Noll, Schenck, and Schimper's "Lehrbuch der Botanik," pp. 335–349.

VII.

THE PTERIDOPHYTES.

The plants of this subdivision approach the common Flowering Plants in their structure much more nearly than any thus far considered. There is a marked differentiation of tissues. True vascular bundles give support to the aërial stalks, and serve to convey the fluids for the nourishment of the plant. A slight tendency to the formation of these differentiated structures has already been noted in the case of the stems of Mosses, but no true vessels are formed in them. From this fact, that their structure is wholly cellular, the plants of the preceding subdivisions are called *cellular cryptogams*. Because of the possession of woody bundles, and because one method of reproduction is by spores and not by seeds, the Pteridophytes are called *vascular cryptogams*. In the Ferns and their allies fully developed fibrovascular bundles, made up largely of spiral and scalariform vessels and

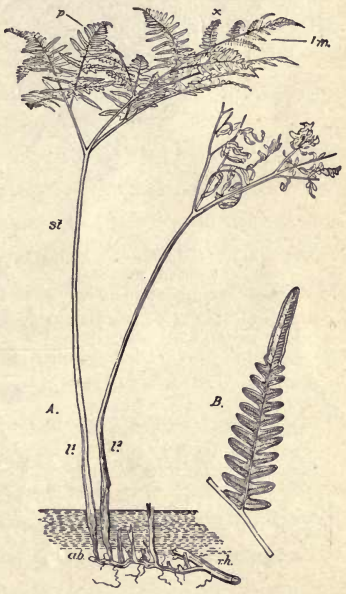

FIG. 109.— *Pteris aquilina*. *rh*, rhizome; *ab*, apical bud; l^1, present year's leaf; l^2, withered leaf of last year; *p*, a pinna; *x*, one of the younger pinnæ, which is seen more highly magnified at *B*. (After Sedgwick and Wilson.)

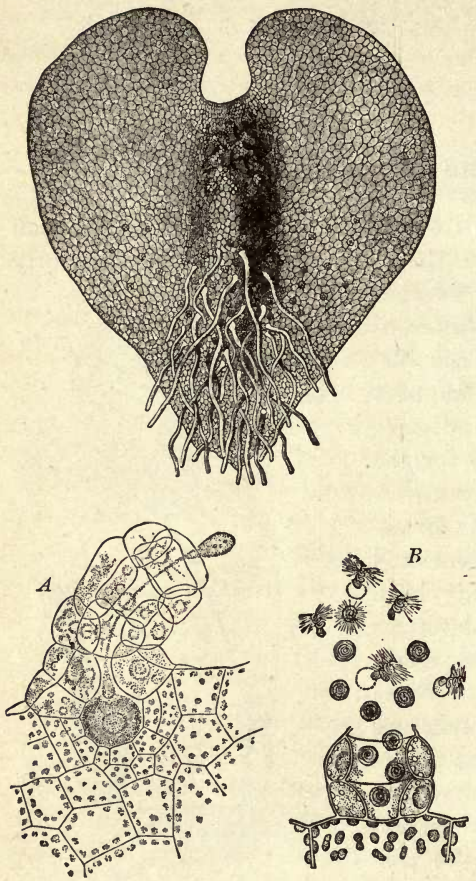

FIG. 110. — Prothallium of a Fern. Among the rhizoids on the lower part of the figure are several antheridia. Above them, near the sinus of the heart, are archegonia. A single antheridium with escaping antherozoids is seen at *B*; an archegonium is seen in section at *A*, showing the egg cell and the tube leading to it. Through the tube a drop of mucilage is being discharged. (After Luerssen.)

sieve tubes, are found. Here, too, for the first time, a distinct, well-differentiated epidermis occurs, with stomata, or breathing pores, resembling those of the higher plants.

In size there is also much advance, for some of the Ferns in tropical climates reach the size of trees. In the arrangement of the wood there is, however, a marked difference from the arrangements in both monocotyledonous and dicotyledonous plants of the highest branch. This is especially noticeable in the shapes and positions of the fibrovascular bundles as seen in transverse sections of the stems. There are also marked differences in the modes of reproduction.

The alternation of generations is clear and distinct. The ordinary form of the plant is the sporophyte. When the spores germinate, there is first formed a protonema which develops into a small thalloid leaf called the *prothallium*. This is usually about an eighth of an inch in diameter. This is the gametophyte; it is inconspicuous and is short lived. The prothallia may be obtained for study from the damp flower pots, walls, or soil of greenhouses in which Ferns are cultivated, or they may be grown by sowing the Fern spores on moist soil, kept protected by a bell glass, and exposed to suitable conditions of light, heat, and moisture. It requires from six to ten weeks to grow the prothallia from the spores. (See Fig. 110.)

If the under side of one of these heart-shaped prothallia be examined under the microscope, special differentiations of the cells will be found near the sinus of the heart; these are the *archegonia* or *pistillidia;* they are rounded aggregations of cells, with a large, centrally situated cell that divides into two. Of these two cells, the lower develops into the egg cell, or oösphere; the upper develops into a tube which becomes filled with a mucilaginous substance that is afterwards discharged, leaving the passage to the oösphere open. (See Fig. 110, *A*.)

More distant from the sinus of the prothallium are the *antheridia*, situated among the root hairs. In these, spirally coiled antherozoids are developed, being finally discharged by the rupture of the cell wall. Accompanying each antherozoid is a small cell, the use of which is not understood. Each antherozoid is provided with cilia, by means of which it swims about when the prothallium is wet. (See Fig. 110, *B*.) It may in this way pass to other prothallia, where, by fertilizing the oösphere, a hybrid variety is produced. If the antherozoids come in contact with the mucilage around the mouth of an archegonium, the mucilage aids in directing them into the tubu-

lar neck leading to the oösphere. By the fertilization of the oösphere a new plant is produced. This plant in turn produces spores. The life history, as just detailed, is believed to be practically the same in all Pteridophytes, though it has not been fully observed in all the species. There are three classes.

CLASS I. THE TRUE FERNS (*Filicinæ*).
CLASS II. THE HORSETAILS (*Equisetinæ*).
CLASS III. THE CLUB MOSSES (*Lycopodinæ*).

CLASS I. **The True Ferns.** — Two groups of plants included here are *heterosporous*, *i.e.*, they have two kinds of spores, female macrospores and male microspores. These are the *Salvinaceæ* and *Marsiliaceæ*. All others are *homosporous* or *isosporous*, *i.e.*, they bear only one kind of spore.

The Ferns, in the narrower sense of the term, are distinguished at once from the other members of this branch by the luxuriance of their leaves. The stem, or rhizome, is underground and develops by the formation of a new bud at one end each year, while it dies away at the older end so as about to keep pace with the new growth. In the spring the young fronds may be seen unrolling themselves, for they are coiled up, or circinate, in the bud. Ferns vary in height from an inch up to many feet, the larger ones, in tropical climates, often raising the rhizome out of the ground to form the trunk of a tree with a tuft of fronds at its top.

On account of the delicate beauty of their fronds, Ferns offer a very attractive field for study. It is estimated that there are from 3000 to 4000 species in all the world. They flourish most abundantly in the torrid zone, decreasing in number and size as one passes from the equator towards the poles. Only 26 species are known to grow within the limits of the Arctic zone, and only 67 species are recorded for the whole of Europe. For North America,

Underwood describes 158 species in "Our Native Ferns and Their Allies." No single locality furnishes a very large number of species.

The Ferns, in the broader sense, include the True Ferns (far the largest number), the *Salvinaceæ*, and the *Marsiliaceæ*. The *Marattiaceæ*, or Ringless Ferns, which are exotic, and found only in greenhouses, and the *Ophioglosseæ* are closely related. The *Ophioglosseæ*, or Adder Tongues, differ from other members of the branch in that the leaves are not circinate in the bud, but are straight or folded, and in their spore cases, which are without rings. They are represented in this country by the Adder Tongues and the Moonworts, *Botrychium*.

THE EAGLE FERN.[1] — PRACTICAL STUDIES.

The **Eagle Fern** (*Pteris aquilina*), or Brake Fern, is probably the most widely distributed of all the Ferns. It grows in all climates, from the torrid zone to the Arctic circle. It is known to thrive as high as 9000 feet above the sea level. In some tropical countries it is said to reach a height of 12 to 14 feet. In New England it varies in height from a few inches in dry barren localities to three or five feet in rich-soiled moist places. Under favorable conditions it grows in such abundance as to form *brakes*, or thickets, whence the common name.

This Fern is easily recognized from the fact that the frond appears to be triply divided. An examination of the frond shows that this is in appearance only, for the two lower branches differ from the pairs above only in size and in being set somewhat forward on the leaf stalk. Specimens for examination should include as much of the underground portions as can be obtained, for it is to be

[1] Practical Studies of almost any other Fern could be added. Any species of Osmunda, Polypodium, or Adiantum would be good.

remembered that the stem is an underground rootstock, or rhizome, and that what is apparently an aërial stem is really the petiole, or stipe, of the leaf. Care should be taken to injure the rhizome as little as possible in removing it from the ground.

1. With the naked eye make an examination of an entire plant. What is the color of the rhizome? Notice the lateral ridges. Does the rhizome branch? How many leaf stalks grow on a branch? Where on the rhizomes are the leaf stalks borne? Do you find remains of the leaves of previous years still attached to the rhizome? Notice the apical bud at the end of the rhizome. If the specimen was dug up in the spring, the apical bud is from half to three fourths of an inch from the base of the season's stipe; later in the season, this bud will have grown into an upright rudimentary stipe which will develop the following season, and a new apical bud will have formed at the end of a new growth of the rhizome. It is

FIG. 111. — *Pteris aquilina*. *A*, a portion of the branching underground stem or rhizome with fine roots; *B*, a young leaf; *C*, a mature leaf. (After Sedgwick and Wilson.)

thus seen that the rhizome increases in length each season only half or three fourths of an inch. Notice the roots. Here true roots are first met in ascending the scale of plant life. The rhizoids of all the lower plants have been single cells or unbranched linear aggregates of cells. The roots of Ferns are solid aggregates; they have an epidermis, and are made up of systems of tissues closely resembling the tissues of the stem. Notice that the roots branch. Do you find hairs on the roots? With a sharp knife make a transverse section of the rhizome. What is the color of the ground tissue — the fundamental parenchyma? Notice the brownish tissue surrounding the rhizome just inside the epidermis; it is composed of lignified cellulose and is known as sclerotic parenchyma or sclerenchyma. Notice two well-defined, almost black areas farther within the stem; they are made up of very hard, strongly lignified cellulose, and are known as sclerotic prosenchyma. Around and between these areas the fibrovascular bundles can be faintly seen by the naked eye as more or less oval areas of tissues slightly darker than the fundamental parenchyma. Draw the section.

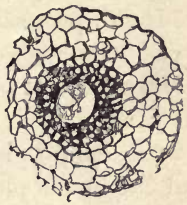

FIG. 112. — Cross section of the root of *Pteris aquilina*. In the center is the fibrovascular bundle; the dense, dark tissue next to the bundle is sclerotic parenchyma; outside of this is fundamental parenchyma, which, together with the imperfectly formed bark, is often broken away in the growth of the root as is seen on the left of the figure.

Notice that the stipe is small near the origin on the rhizome, enlarges considerably as it approaches the surface of the ground, and diminishes gradually as it rises above the surface. Of what advantage to the plant is the enlargement? Cut a cross section of the stipe. Draw it. Notice the appearance of the tissues in the section. An imagined resemblance of these tissues to an eagle with

outspread wings was the origin of the name *Eagle Fern*. All above the lowest branches of the stipe is known as the lamina or leaf. The leaf is pinnately and bipinnately divided. Find, if possible, a fruiting frond. The sporangia are borne around the margin of the under side of the frond, protected by an indusium formed by the folding over of the edge of the leaf.

Draw a plant of Pteris, showing distinctly all its different parts.

2. Examine a longitudinal horizontal section of an apical bud cut in the plane of the lateral ridges from a specimen imbedded in celloidin. Find the apical cell in the hollow at the end; as seen in section it is a triangle with rounded base. (See Fig. 113, *A*.) This cell divides by the splitting off of cells first from one side, then from the other side. These cells are known as segmental cells; they divide and subdivide to form new cells. Every cell in the rhizome has originated through the segmental cells from the apical cell. It requires care and skill to secure sections showing the apical cell.

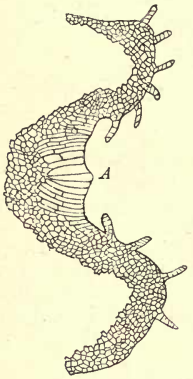

FIG. 113. — Horizontal longitudinal section of the apical bud of *Pteris aquilina*, showing the apical cell at *A* in process of dividing. (× 480.)

The cells which extend for a short distance within and around the segmental cell are thin walled and make up an actively growing tissue known as the apical meristem. As this tissue continues to grow, its cells become differently differentiated and develop into the various tissues of the rhizome.

Examine a vertical longitudinal section of an apical bud. The apical cell, if included in the section, will be seen to be polygonal in shape. (See Fig. 114, *A*.) This section will serve well for a study of the different tissues

that have resulted from the differentiation of the cells of the apical meristem. Starting from the centrally situated ground parenchyma, and passing either to the top or the bottom of the rhizome, make out the following succession of tissues:

a. A fibrovascular bundle. The row of cells which separates this from the ground parenchyma is known as the bundle sheath. Then come sieve tubes with the surfaces marked by irregular areas of perforations. Next are wide scalariform vessels with distinct markings somewhat resembling the rungs of a ladder. In the center of the bundle are spiral vessels, *i.e.*, vessels with the cell wall strengthened by a band of cellulose running spirally around on the inside. These will not be seen, of course, unless the section passes through the center of the bundle. Outside the spiral vessels the order is reversed, and scalariform vessels, sieve tubes, and bundle sheath are again seen.

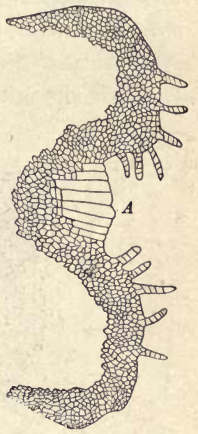

FIG. 114. — Vertical longitudinal section of the apical bud of *Pteris aquilina*, showing the apical cell at *A* in process of dividing. (× 480.)

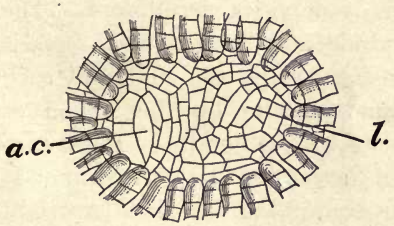

FIG. 115. — *a.c.*, an apical cell of *Pteris aquilina* seen in vertical transverse section. The apical bud was on the point of dividing, and a second apical cell is seen at *l*. (After Sachs.)

b. Next outside the fibrovascular bundle is another region of ground parenchyma. Following this is a region of the thick-walled cells of the sclerenchyma. Then more ground parenchyma, which may happen to include another fibrovascular bundle. Then come the thick-walled cells of the

hypodermis. Last lies the single row of cells of the epidermis. Draw the section and indicate by letters all the tissues you have been able to make out.

3. Boil an apical bud in Schultze's macerating mixture a few minutes, dissect it with needles, and make a careful study of the scalariform and spiral vessels and sieve tubes of the fibrovascular bundles, and of the cells of the sclerenchyma which are thick walled, pitted, and pointed at both ends.

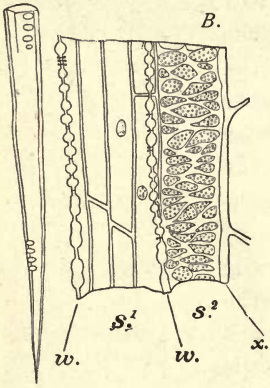

FIG. 116. — Cells from the rhizome of *Pteris aquilina*. At the left is seen the pointed end of a sieve tube; *B*, two sieve tubes, S^1 and S^2, cut lengthwise; S^2 shows the back surface of the tube covered with sieve plates; the back surface of S^1 shows only two small sieve plates, but its side walls, *w*, *w*, show sections through sieve plates. (After De Bary.)

Treat a portion of an older part of the rhizome with Schultze's macerating mixture, and make similar studies of its tissues.

The various vessels of the fibrovascular bundles and the elongated cells of the sclerenchyma have been built up by the breaking away of the end walls and the fusion of a number of cells into one. The markings on their walls result from strengthening deposits of cellulose. The spiral and scalariform vessels which occupy the center of each bundle make up the xylem or wood of the bundle. These vessels are filled only with air. It is believed that the water containing dissolved nutrient material from the soil finds passage to the upper portions of the plant through the walls of these vessels. The sieve tubes and similar vessels completely encase the xylem; they are known as the phloëm or bark of the bundle. Descending currents of nutrient material elaborated in the leaves find passage in the phloëm to

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all portions of the plant that do not contain chlorophyl. The fibrovascular bundles form continuous conduits from the smallest rootlets up through the rhizome and stipe, and send their branches into the divisions and subdivisions of the leaves. Externally they may be traced as the ribs and veins of the leaves. The possession of the fibrovascular bundles forms, as already stated, a marked line of separation between the cellular plants of the lower subdivisions and the vascular plants of the Pteridophytes and the higher Flowering Plants.

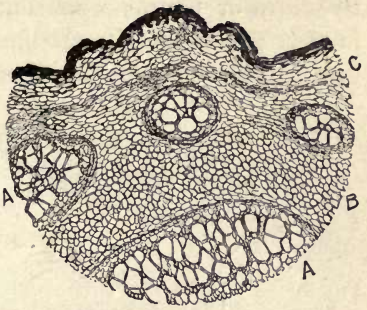


FIG. 117. — Part of a transverse section of the rhizome of *Pteris aquilina*. *A*, *A*, fibrovascular bundles; *B*, fundamental parenchyma; *C*, sclerotic parenchyma or hypodermis.

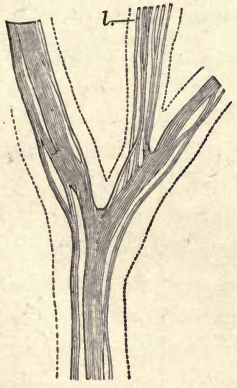


FIG. 118. — Diagram showing the branching and interlacing of the fibrovascular bundle in the upper side of the rhizome of *Pteris aquilina*. *l* shows the origin of a leaf. (After Sachs.)

4. Examine under low power a cross section of the rhizome. Draw the section and locate by letters the epidermis, hypodermal tissue, ground parenchyma, sclerenchyma, bundle sheath, scalariform and spiral vessels, and intercellular spaces.

Treat a section with Schultze's solution. Draw, and locate by letters the portions containing lignified cellular tissue.

Treat a section with iodine solution. What tissues contain starch? These tissues serve as storehouses for the reserve food of the plant. Stain a section, cut after imbedding in celloidin, in picro-carmine for

twenty-four hours; wash out the carmine and stain with methyl green for fifteen minutes. Wash out excess of green in alcohol, clear in oil of cedar, and mount in Canada balsam as a permanent preparation.

FIG. 119. — A leaflet of *Pteris aquilina*, showing the venation. (After Luerssen.)

5. Treat pieces of the stipe with Schultze's macerating mixture, dissect, and find and name as many tissues as you can.

6. Tear off a bit of the epidermis of the under side of the leaf, taking care to secure some from over the veins and some from between the veins. Sketch some of each of the different kinds of cells you find, lettering the sketch to show where each kind of cell is located. Notice the stomata, each inclosed by two guard cells. The stomata are the breathing pores of the leaf. Affected by variations in moisture and light, the guard cells change their form and open or close the entrance, thus regulating the admission of oxygen and carbon dioxide to some extent, and controlling the evaporation of the water according to the necessities of the plant. Do you find nuclei in the guard cells? Do you find chlorophyl bodies in them? Do you find nuclei and chlorophyl bodies in the epidermal cells?

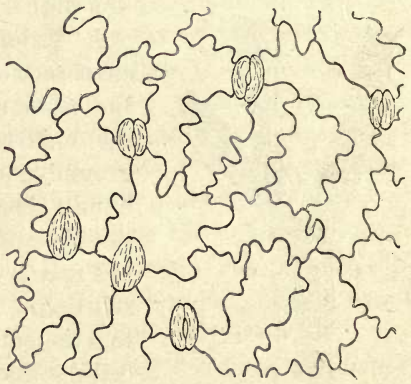


FIG. 120. — Cells from the under surface of the leaf of *Pteris aquilina*, showing stomata. (× 480.)

Examine a piece of the epidermis torn from the upper side of the leaf. Draw a few cells. State how it differs from the epidermis of the lower side.

7. Hold pieces of the leaf between pieces of pith and cut cross sections. Draw a portion of a section showing a fibrovascular bundle. Beginning on the upper side, notice the epidermis, a single row of cells; under these, green cells standing perpendicularly to the epidermis, columnar parenchyma; then other similar green cells irregularly arranged and having intercellular spaces between them; on the lower side of the leaf a single row of cells forming the epidermis. Find sections through

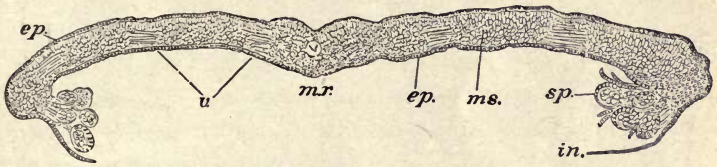


FIG. 121. — A fertile leaflet of *Pteris aquilina* seen in cross section. *sp*, sporangia; *in*, indusium; *ms*, mesophyll or loose parenchyma; *mr*, midrib; *v*, veins. (After Sedgwick and Wilson.)

stomata in the lower epidermis, and notice that each stoma opens into a large intercellular space, or breathing chamber. The chlorophyl-bearing cells of the interior of the leaf are called *mesophyll.* Do they contain starch?

8. Examine the sporangia. These may be obtained by dissecting off the indusium and scraping the sporangia from the margin of the leaf. A sporangium closely resembles an interrogation point (?) in shape. Notice the pedicel, or stalk, the annulus of thick-walled cells which extends from the top of the pedicel up one side and over the top of the sporangium, and the thin-walled cells inclosing the body of the sporangium. Draw. When the sporangium is ripe, the thick-walled cells of the annulus become dry and contract; this causes the thin-walled cells

of the opposite side to break apart and scatter out the spores.

Imbed pieces of a fruiting frond between pieces of pith and cut cross sections. Study the sporangia *in situ* in these sections. Observe the position of the indusium.

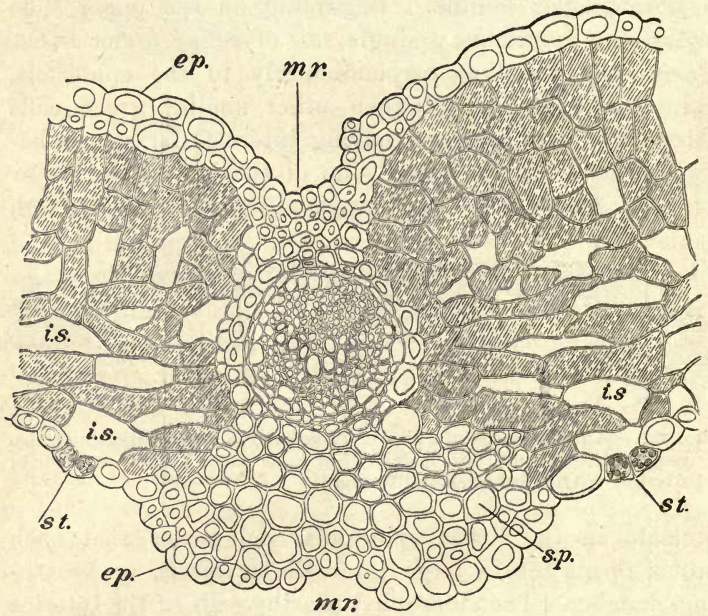


FIG. 122. — Cross section of the midrib and adjacent parts of a leaflet of *Pteris aquilina*. The fibrovascular bundle of the midrib is seen in the center, supported above and below by prosenchyma, i.e., cells with greatly thickened walls; *i.s*, intercellular spaces; *st*, stomata; *ep*, epidermis. (After Sedgwick and Wilson.)

Distinguish between the outer indusium formed by the folding over of the edge of the leaf, and the inner or true indusium formed by an extension of the epidermis of the under side of the leaf. Draw.

If fruiting fronds of Pteris are not easily obtainable, substitute the sporangia of some other Fern; for example, one of the shield Ferns.

9. Examine the spores. What is their shape? What is the character of their covering? Crush some of the spores by pressure on the cover glass. Treat with Schultze's solution. Of what is the covering or *exospore* composed? Treat another mount of crushed spores with iodine solution. Do they contain starch? Do you find a nucleus?

10. Study the protonemæ. These are easily cultivated as follows: Sow the Fern spores on a fresh moist sod placed in the bottom of a glass jar; also on the moist sides of the jar, and on a sheet of glass to be used as a cover to the jar. As Fern spores usually require a period of rest before they will germinate, use spores of the previous year. Keep this moist chamber under suitable conditions of heat and moisture, but not in too strong sunlight. The spores will begin to germinate in about a week, and the progress of the growth may be watched by making examinations at intervals of a few days. Draw specimens showing successive stages of development. Notice that the growth begins by the bursting of the spore covering. Notice that a rhizoid begins to form simultaneously with the first division of the spore contents, and that other rhizoids are formed later. Do the cells of the protonema contain nuclei? Do they contain chromatophores? Starch? Find protonemæ that show at the distal end a triangular apical cell resembling the apical cell of the apical bud; it may not be easy to do this. Notice that the cells of the protonema are at first

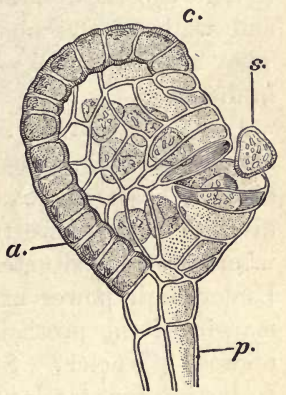


FIG. 123.—A sporangium of *Pteris serrulata*. *s*, a spore; *c*, capsule; *a*, annulus; *p*, pedicel. (After Suminski.)

arranged to form a linear aggregate; this arrangement is succeeded by a superficial aggregate, and this by a solid aggregate. In passing through these stages the protonema is gradually transformed into the prothallium, which is the gametophyte form of the plant. (See Figs. 124, 125, 126, 127, 110.)

FIG. 124. — A spore of *Pteris serrulata*. (After Suminski.)

11. If the cultivation of Number 10 has not produced prothallia in from six to ten weeks, search for them on the Fern pots, the ground, and walls of greenhouses where Ferns are cultivated. They are very small — one eighth to one third of an inch in diameter.

Under low power draw the prothallium as seen from above, and again as seen from the under side. Notice the distinct heart shape. Does this recall the dichotomous division of Liverworts? Do you find rhizoids? If so, where are they situated? Why are they not true roots? Under high power examine some of the cells near the margin of the prothallium. Do they contain chromatophores? Nuclei? Starch? In testing for starch use prothallia that have been kept in alcohol.

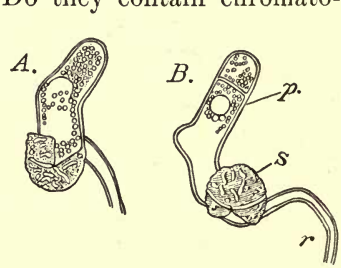
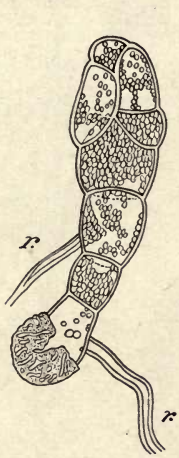


FIG. 125. — *A*, a spore of *Pteris serrulata* after it has begun to germinate; *B*, the same, farther advanced; *S*, the spore; *r*, the rhizoid; *p*, the young protonema. (After Suminski.)

With the high power search the region just below the sinus of the heart on the under side of the prothallium for archegonia. (See Fig. 110.) They are borne on a thickened region of meristematic tissue called the *cushion*. What is their shape? Of how many cells does each consist? Can you find the canal or opening into the archegonium? Draw.

Search among the rhizoids for spherical antheridia. Draw. It is possible that antherozoids will be found swimming in the water. These are spirally coiled organisms, having a number of cilia at the small end; a spherical body is often seen attached to the larger end. The antherozoids swim to the canal of the archegonium, effect an entrance, and fertilize the egg cell. (See Fig. 110, *A* and *B*.) The egg cell now develops by successive cell



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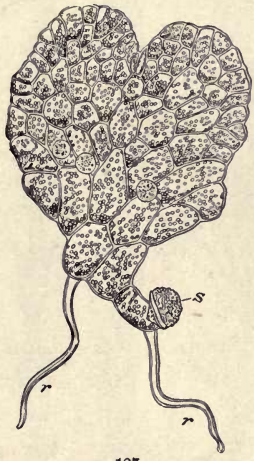

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FIG. 126. — The same as Fig. 125, somewhat farther advanced. (After Suminski.)

FIG. 127. — The same as Fig. 126, but the protonema has now developed into a young prothallium. A fully developed prothallium is shown in Fig. 110. (After Suminski.)

divisions, and produces a new Fern plant with rhizome, roots, and frond. The new plant remains attached to the prothallium for a time, but finally becomes separated and lives as an independent plant.

References for Reading. — Sedgwick and Wilson's "Biology," pp. 105–155; Parker's "Elementary Biology," pp. 344–362; Bidgood's "Elementary Biology," pp. 112–144; Goebel's "Classification of Plants," pp. 189–245; Vines' "Text-Book of Botany," pp. 372–415; Bennett and Murray's "Cryptogamic Botany," pp. 10–95, 119–124;

Bower's "Practical Botany," pp. 287–318; Huxley and Martin's "Elementary Biology," pp. 443–459; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 103–129; Dodge's "Practical Biology," pp. 320–335; Strasburger and Hillhouse's "Practical Botany," pp. 287–297; Carpenter's "The Microscope," pp. 599–605; Underwood's "Our Native Ferns and Their Allies"; Atkinson's "Biology of Ferns"; Strasburger, Noll, Schenck and Schimper's "Lehrbuch der Botanik," pp. 349–372.

FIG. 128.—*Equisetum arvense.* 1, a barren plant; 2, fertile plant; 3, a spike of sporangiophores of *Equisetum arvense;* 4, a single sporangiophore; 5, a spore with elaters extended; 6, spore with elaters wrapped around it; 7, a fertile plant of *Equisetum sylvaticum;* 8, a prothallium of Equisetum. (After Kerner and Oliver.)

CLASS II. **The Horsetails** (*Equisetinæ*). — There is now only one order in this class, and this is homosporous.

In the carboniferous age of the world's history there were many genera, as is evidenced by the remains found in the coal formations, and among these heterosporous forms are known to have existed.

The stem of Equisetum is subterranean. From it hollow vertical shoots rise; some sterile, bearing only leaves and branches; others bearing sporangia, which are located on the inner sides of scales grouped together into cone-shaped tips of the shoots. The ripe spore cases open on the inner side. The spores are greenish in color; each has four threads, or elaters, with knob-shaped ends, which are wound round the spore when moist, but are extended when dry; in other words they are hygrometric. These threads undoubtedly help in the transportation of the spore. These spores are of great interest under the microscope. The moisture of the breath upon them when dry causes the elaters to fold up. When the moisture evaporates, they again extend themselves.

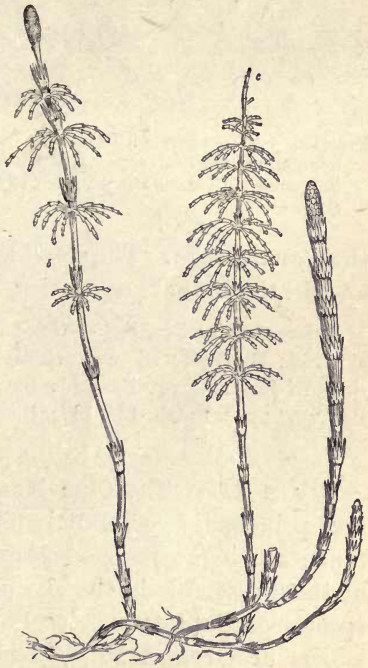

FIG. 129. — *Equisetum sylvaticum.* In the center is a barren branch. On the right and left are fertile branches. (After Bennett and Murray.)

The cylindrical shoots are hollow, the woody tissues being arranged in a single circle of fibrovascular bundles. The epidermis contains silica to such an extent that it

may be boiled for some time in strong nitric acid without losing its shape. All the organic matter is thus removed, and the skeleton of the stem remains in pure silica — a most beautiful object when seen under polarized light. It not only shows the general structure of the epidermis, but preserves the stomata with their guard cells. The small leaves are arranged in whorls, and, in the branching species, the branches are in whorls.

FIG. 130. — *A*, a spore of Equisetum with the elaters closely wrapped about it; *B*, the same with elaters extended. (After Carpenter.)

References for Reading. — Goebel's "Classification of Plants," pp. 256–273; Parker's "Elementary Biology," pp. 366–368; Vines' "Text-Book of Botany," pp. 416–420; Bennett and Murray's "Cryptogamic Botany," pp. 100–113, 124–130; Bower's "Practical Botany," pp. 325–340.

CLASS III. **The Club Mosses** (*Lycopodinæ*). — These are principally perennial plants with creeping stems. Some are homosporous, others are heterosporous. Some of them resemble in the character of their leaves different species of Conifers so closely that they have the common names of Ground Pine, Running Pine, Ground Cedar, and Ground Fir. The resemblance is still further carried out in the conelike spikes that some species bear on upright branches. These spikes are made up of scalelike leaves, each bearing on the inner side near the base a somewhat kidney-shaped spore case which, when ripe, opens transversely near the upper part and discharges quantities of fine sulphur-colored spores, all of one kind. The first stage of the development of the Club Mosses from the spores is little understood, as the prothallia have been seen and studied in only a few species. The spores contain a large amount of oil, so that they are very in-

flammable. They have been extensively used, under the name of lycopodium powder, to produce flash lights.

There are about 100 species of the larger Club Mosses in all the world, the greater number growing in the tropics. About eleven species grow within the limits of the United States, the most common ones with us being *Lycopodium dendroideum*, or Ground Pine, *L. clava-*

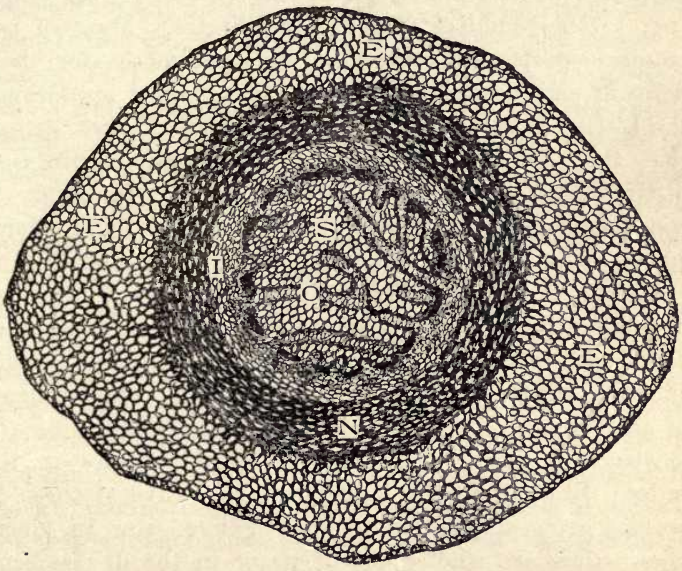

FIG. 131. — Transverse section of stem of *Lycopodium complanatum*. *E*, *E*. *E*, cortex; *N*, sclerenchyma; *I*, fibrovascular bundle sheath; *S*, phloëm portion; *O*, xylem portion of the central fibrovascular bundle. (× 60.)

tum, or Running Pine, and *L. complanatum*, sometimes spoken of as Ground Fir or Ground Cedar.

The plants of this order, while somewhat resembling the Mosses in outward appearance, differ from them in the character of their fructification and in their higher organization. The stems show centrally situated, well-defined fibrovascular bundles which may be traced into the

leaves. In these two particulars they clearly resemble the Ferns with which they are classed as allies. The name of the order is from two Greek words meaning wolf foot, though the reason is not apparent why this name should be given to these plants. It was possibly suggested by the short hairy branches of *Lycopodium clavatum*.

The Lycopodinæ include the **Little Club Mosses** (*Selaginelleæ*), which number about 335 species, mostly tropical; seven are native to the United States. Many of the tropical species are cultivated in greenhouses for their delicate and beautiful foliage. In outward appearance the Little Club Mosses resemble the Club Mosses, except that they are much smaller. The characteristic that distinguishes them is the production of two kinds of spores, macrospores, usually four in number, and microspores, of indefinite number.[1]

Here also are included the *Isoëteæ*, or the **Quillworts.** The scientific name is from two Greek words meaning equal and year; it is appropriate, as these plants remain the same throughout the whole year. The common name is also appropriate because of the resemblance of the leaves to quills. There are about 50 species in the order; 16 occur in the United States. Five of these 16 species grow submerged in water; five grow in places where they are wholly out of water in the dry season; the others grow partly in and partly out of water. The leaves grow in bunches from a sort of bulb, varying in number from 10 to 100, and in length from 2 to 20 inches.

References for Reading. — Goebel's "Classification of Plants," pp. 274–297; Parker's "Elementary Biology," pp. 371–373; Vines' "Text-Book of Botany," pp. 421–430; Bennett and Murray's "Cryptogamic Botany," pp. 38–63, 115–119; Bower's "Practical Botany," pp. 261–286.

[1] If time permits, arrange Practical Studies on the Horsetails, Club Mosses, and Little Club Mosses.

VIII.

THE SPERMAPHYTES.

The eighth subdivision includes the higher and so-called Flowering Plants. They vary in size from plants a small fraction of an inch in height up to the mightiest trees. They are, in general, plants of a highly differentiated and complex structure. The plant is the sporophyte. There are two kinds of spores, *microspores* or *pollen grains*, and *macrospores* borne in embryo sacs. The contents of the pollen grain develop by cell division into a minute prothallium which takes the form of a tube projecting from the pollen cell. The contents of the embryo sac also develop into a minute prothallium. These prothallia represent the gametophyte. The first step in the reproduction is the extension of the pollen tube, which is an outgrowth of the inner coating of the pollen grains, into the embryo sac, contact with the viscid secretion of the stigma being a necessary prerequisite to the growth of the pollen tube. As the pollen grains are not self-motile, nature provides for their transportation from the anther to the stigma, by means of the wind, by the adaptation of the various parts of the flowers to this end, and by rendering the flowers attractive to various insects, either because of the nectar which furnishes food for the insects or because of their colors which attract or serve as a means for concealment or protection for them. These little creatures carry the pollen from anther to stigma on the same or on different flowers.

The feature that especially distinguishes the Spermaphytes from the plants of the seven preceding subdivi-

sions is the production of true seeds, which are the result of the fertilization of the embryo cell by the receipt of the contents of the pollen cell. The embryo cell is borne in a pistil, and the pistil or pistils of a flower are known as the *gynœcium*; the stamens with their pollen-bearing anthers constitute the *andrœcium*. According as the embryo cells or ovules are exposed to the direct action of the pollen grains, or are borne in closed ovaries, the Spermaphytes are divided into two classes:

CLASS I. THE GYMNOSPERMS.
CLASS II. THE ANGIOSPERMS.

CLASS I. **The Gymnosperms.** — In these the ovules are borne on the lower part of the inner surface of modified leaves which form a cone or female flower; the pollen is also borne on modified leaves forming a small cone or male flower. At the season of fertilization the ovules are exposed to the air, the pollen falls directly upon them, and they are fertilized by the passing of the contents of the pollen grains into the ovules through tubes which develop from the inner coat of the pollen grains. The leaves of the cone then close, remain closed during the development, and open at maturity to discharge the seed. The Gymnosperms include the Cycads, which are native in hot climates; the Conifers, which include the Pines and related trees and which are native in temperate and cold climates; and the Joint Firs, which are native in hot climates.

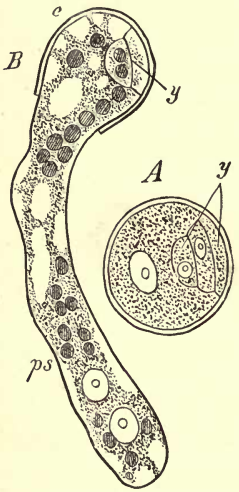

FIG. 132.—*A*, a pollen grain of the Gymnosperm, *Ceratozamia longifolia*, on the point of beginning to develop; *B*, the same after the tube has partially developed. (After Juranyi.)

THE PINES. — PRACTICAL STUDIES.

1. Examine any Pine tree as it grows. Is the stem excurrent, *i.e.*, does it rise as a central main shaft, or is it deliquescent, *i.e.*, does it divide and subdivide into branches? Are the branches arranged in any particular way on the stem? If so, state what the arrangement is. Examine the apical bud at the end of each branch; also around its base several lateral buds. The apical bud develops into the shoot of the next season; the lateral buds develop into the new branches. Starting with the top of a young Pine, can you tell how much is this season's growth? Can you trace the growth of the different years down the stem? Cut across the stem where it is at least half an inch in diameter. Count the number of rings of annual growth. How does this number compare with the age as determined by tracing the growth of the different years down the stem? Notice the color of the bark. Is the bark on the stem and also on the branches smooth or rough? Observe the scale leaves on the branches. Notice that the foliage leaves are produced on short dwarf branches. Describe the surface of the dwarf branches. How many leaves grow on a branch? Notice the sheath at the base of the leaves. Examine different Pine trees. Is the number of leaves on a dwarf branch the same in the different species? Identify the species studied by consulting Gray's "Manual."

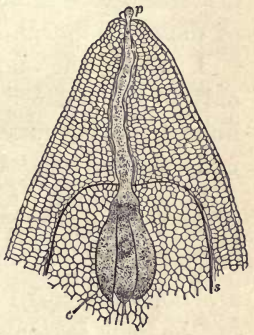

FIG. 133.—Longitudinal section of the nucellus of the naked ovule of the Gymnosperm, *Juniperus Virginiana*. *p* is a pollen grain which is sending its tube down into the ovule. (After Strasburger.)

2. Dig up some very young Pines — those of the present season's production, for instance. Is there a central taproot, or is the main root lost by division into branches? Compare with the root of a tree three or four years old. Describe the mode of branching. Notice and describe the rootlets. Draw enough to give a good idea of the gross morphology of the root.

3. Study the male flowers. These are to be obtained only in the spring. They mature in May or June. Alcoholic material may be used for the observations. The male flowers may be obtained from various species, but are most surely to be found on the Scotch Pine, the Austrian Pine, and the Red or Norway Pine, descriptions of which are given in various botanies. The male flowers are borne as small yellow cones at the base of the shoot of the new season's growth. Are these cones sessile, or are they borne on stalks? Draw an entire cone. Is there any definite arrangement of the modified leaves which compose the cone? Are these leaves, the stamens, sessile or borne on stalks? Remove some of the stamens and examine them for the pollen sacs. On which surface of the stamens, and where on the surface, are the pollen sacs borne? What is the shape of the pollen sacs? Find mature specimens. How do the pollen sacs open? Draw, showing an entire stamen. Examine under high power some of the pollen grains. Draw. Apply reagents, if necessary, and determine whether there is a nucleus and nucleolus. Is starch present? Is oil present? If starch and oil are present, are they evenly distributed in all parts of the grain? Make out two coats in the cell wall. Prove that the outer is composed of lignified cellulose and the inner of normal cellulose. When the pollen grain develops in contact with the ovule, the inner coat grows into the tube which penetrates the micropyle of the ovule.

4. Study the female flowers. These are borne near the very tip of the new shoot as pinkish-green cones. They are to be gathered in June. Are these cones sessile, or borne on stalks? Draw a cone. Dissect a cone. Notice that the modified leaves are of two kinds. The thin and small scale leaf or bract corresponds to an ordinary leaf; the thicker scale or carpel bears ovules. Draw a bract. Where on the carpel are the ovules situated? Draw a carpel, showing the ovules. The ridgelike projection of the carpel is called the keel; its function is to guide the pollen grains towards the ovules.

5. Study the development of the ovule into the seed. Two years are required for this. Branches of Scotch, Austrian, or Red Pine may be found in the early part of the summer bearing the cones at three stages of development: *a*. The female flowers, already studied, at the apex of the new shoot. *b*. Cones one year old at the apex of the shoot of the preceding year. *c*. Cones in the second year of their growth at the apex of the two-years-old shoot.

What is the position of the ovules on the carpels of the youngest cone? Find on each ovule the micropyle — a small opening into the interior through which the pollen tube enters. Where on the ovule is it situated? Make a section of an ovule through the micropyle; with a hand magnifier or low power distinguish the *integument* or outer coat; next within the integument is the *nucellus*, composed of parenchyma; near the end of this mass of parenchyma farthest away from the micropyle is situated the *embryo sac*, which is a large cell containing more or less of a very soft tissue — the *endosperm*. Draw.

Dissect a year-old cone. Make a section of a seed through the micropyle. Compare the micropyle, integument, embryo sac, and its contents with the same parts in the youngest cone. Draw.

Obtain the ripe or nearly ripe seeds from a two-years-old cone. Notice the wings and the markings on the surface of the seed. Of what use are the wings? Make a section of a seed through the micropyle, and compare with the observations made on the first and second year cones. The integument has thickened greatly, and now consists of two coats; the nucellus has almost disappeared; the endosperm has increased in amount and firmness because of the accumulated food supply for the new plant. Macerate the endosperm in caustic potash and dissect it with needles. Make out the embryo, and in it a number of cotyledons and a radicle.

6. Make thin longitudinal sections of an apical bud — that is, the winter bud from which the next year's new shoot will develop — which has been preserved in alcohol. Mount in Schultze's solution all of the sections that are cut through or nearly through the apex. Examine under both low and high powers. Notice the thin-walled cells, abundantly supplied with protoplasm, at the apex. In the acrogenously growing plants of the lower subdivisions up to the Lycopods, the growth in length originates in the division of an apical cell. In the Phanerogams the thin-walled cells near the apex of the stem are capable of division. From their division arises the growth of the plant in length. The apex of the stem is, therefore, called the *growing apex* or the *punctum vegetationis*. The newly formed tissue at and near the apex is the *primary meristem*. Trace the differentiation of these cells as far back as your section permits. Do you find tracheïdes and spiral vessels?

7. Study the foliage leaves. Measure a number of leaves on each of two or three species of Pine. State the average length for each species examined. What is the shape of the end? Notice rows of dots, the stomata, running lengthwise the leaves. With a sharp razor cut

off a thin slice of the epidermis, mount in water, and examine the stomata under high power. Run the finger over the edges of the leaves. What is noted? Cut cross sections of the leaves of different species. What is the shape of the cross section in each case? Examine with a magnifying glass and draw, showing all you see. Measure or estimate the greatest diameter of the leaves.

Study Fig. 134, which is a picture of a thin cross section of the leaf of the Red Pine, *Pinus resinosa*, or Norway Pine. Around the outside is a single layer of cells with thick walls, *A*, the epidermis. This covering of thickened tissue protects the softer interior of the leaf. At the corners, *B* and *B*, are large cells whose irregularity causes the roughness of the edges. Just within the epidermis is another narrow band of thick-walled cells, the hypoderma, *C*. Within this is a broad band of delicate parenchyma with folded cell walls, *D*. This is the mesophyll. When the leaf was living these cells were filled with protoplasm bearing green chlorophyl bodies. Situated in the mesophyll are five large resin ducts, *E*, each surrounded by a row of glandular cells which secreted the resin. Next within is an elliptical ring of oval cells, *F*, the endodermis, or bundle sheath. The bundle sheath incloses thin-walled parenchyma, *G*, which did not contain chlorophyl, and two fibrovascular bundles. Each fibrovascular bundle consists of two parts. The woody part or xylem is situated towards the flat or upper

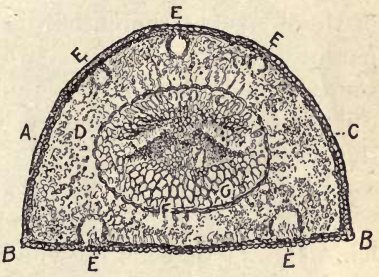

FIG. 134. — Leaf of Red Pine, *Pinus resinosa*. Transverse section. *A*, epidermis; *B*, *B*, enlarged corner cells; *C*, hypoderma; *D*, mesophyll; *E*, resin ducts; *F*, bundle sheath; *G*, colorless parenchyma.

side of the leaf. The bark portion, or phloëm, is situated towards the lower or outer, rounded side of the leaf.

Mount in Schultze's solution thin cross sections of leaves of different species of Pine, cut after imbedding in paraffin or celloidin.[1] Comparing with Fig. 134, locate on a drawing of the section all the parts mentioned above. The whole section should be drawn in outline, but it will be sufficient if the details are drawn in only half of it. In what portions of the section is the cellulose lignified? Notice under high power that the epidermis is composed of three layers: the cuticle is the outer, thin and transparent coating; the other two coatings are thick walled. Can you make out cracks running from the centers of the cells outward through these walls? Find places where the section passes through a stoma; observe the guard cells, and the air chamber into which the stoma opens.

Trace the hypoderma around the section. Is the number of rows of cells of which it is composed constant? How many rows do you find? Observe the hypoderma beneath a stoma; what do you notice?

Tie a number of fresh leaves together with thread tightly. Imbed the bundle in pith and cut cross sections. Mount in water and examine the mesophyll. Observe the abundant chlorophyl. Determine if it bears starch. Notice the folded walls of the cells.

Observe the thin-walled parenchyma within the bundle sheath. Does it bear chlorophyl and starch? What is the prevailing shape of the cells as seen in cross section?

Draw under high power the xylem and phloëm as seen in the section which was mounted in Schultze's solution. Also draw a portion of the bundle sheath. What do you find to be the contents of the cells of the bundle sheath in a section from a fresh leaf?

[1] For methods of preparation, see the author's "Practical Methods in Microscopy," Chap. VII.

8. Study Fig. 135, which is a cross section of the stem of the White Pine, *Pinus strobus*, cut in July of the second year of its growth. On the upper side of the picture is the epidermis, *A*, which is smooth in the young branches, but becomes covered, at a later period, with brown scales that result from the dying of the earlier bark. Within the epidermis is a broad band, *E*, which includes two or three rows of rectangular (as seen in section) cells of the cork layer, *B*; the cortical parenchyma, *C*, which makes up the greater part of the band; and resin ducts, *F*, each surrounded by layers of epithelial or glandular cells whose function is to secrete the resin or pitch. On the inner side, the cells of the cortical layer pass into the cells of the irregular layer, *D*, the true phloëm. Again there is a gradual transition to the cells of the cambium layer, *G*. All the tissues thus far mentioned up to and including the outer part of the cambium layer make up the bark. Inside the cambium is a broad layer, *H*, of the new wood formed during the second year's growth; inside of that is another broad layer, *I*, of wood that was formed by the growth of the first year. The two layers, *H* and *I*, and the inner part of the cambium layer, constitute the xylem or wood. In the layer, *I*, are

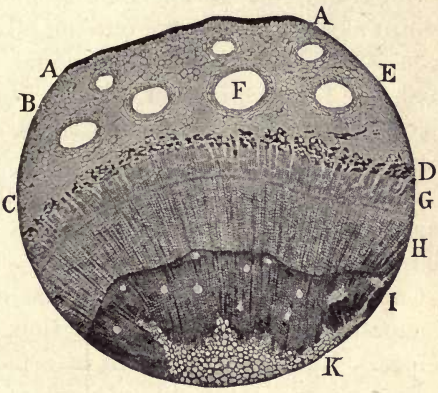

FIG. 135. — White Pine, *Pinus strobus*. Transverse section of a stem in the second year of growth. *A*, epidermis; *B*, cork layer; *C*, cortical parenchyma; *D*, phloëm; *F*, resin ducts; *G*, cambium layer; *H*, wood in process of formation in the second year; *I*, wood formed during the first year. (× 35.)

several small resin ducts. The narrow dark lines running in the radial direction through the xylem, and even extending out through the cambium layer into the phloëm, are the beginnings of medullary rays. In the central part of the stem is the pith parenchyma, *K*. The projections of the pith parenchyma into the xylem are the places of origin of branches which developed just above the plane of this section.

Cut transverse sections of a second year stem that has lain in alcohol to dissolve out the pitch and has afterward been softened by soaking in equal parts of alcohol and glycerine for twenty-four hours. Do not try to get complete sections, but get thin cuttings, showing all the parts from the epidermis to the pith. Mount in Schultze's solution, and identify under low power all the above-mentioned parts. Draw enough of the section to locate everything observed.

Cut similar transverse sections of first year shoots. Compare with the preceding section. Draw a portion as before. Cut similar sections of a piece of the stem that is four or five years old. Compare with the other two, drawing a portion as before.

Under high power examine the cambium layer in a delicate section. In this layer the growth of the stem in thickness originates. Find in this layer cells with very thin walls. Draw a few. What is their shape? During the period of growth the cells undergo rapid fission in the tangential direction: the outer halves developing into the various tissues of the bark; the inner halves into the wood. From this layer follow out into the phloëm. What changes do the cells undergo as they increase in age? Are the changes abrupt or gradual? Starting again with the thinnest cells of the cambium layer, trace the development of the cells into the xylem, stating what you observe. Compare with the changes on the

outer side of the cambium layer. Which are the more abrupt?

Examine the cells of the cortical parenchyma. What is their prevailing shape? Do you find intercellular spaces?

Consider the resin ducts. The study of the development of young shoots shows that the resin ducts are intercellular spaces which have arisen by the gradual drawing apart of the cells to make room for the resin as it is secreted. Examine the cells of the two inner rows of glandular cells next to the duct. In these cells the resin was secreted. What is the shape of these cells? Examine the rows of cells next outside. In these cells starch was stored up to be changed into resin by the action of the cells of the two inner rows. Draw a resin duct with its glandular cells under suitable power.

Examine the cells of the cork layer. What is their shape? Draw a few. In this layer, cell division goes on to a limited extent.

Study the xylem under high power. The cells here seen in cross section are known as tracheïdes of the wood. Draw a few. Find places where three separate layers may be made out in the cell wall. Draw. Find on the radial walls places where the layers have separated and present somewhat the appearance of a double-convex lens seen in section. These are sections through bordered pits.

Trace a medullary ray from the pith parenchyma out into the cortical parenchyma. Those that can be so traced were the first to originate, and are called primary medullary rays. There are others that extend only part way from the pith to the cortex; these formed later and are called *secondary medullary rays*. The medullary rays originate in the crowding together of the older cells by the rapidly forming new cells of the cambium.

Examine a resin duct in the xylem and compare its structure with the resin ducts of the cortex. Draw.

These resin ducts are connected with the cortical resin ducts by channels through the medullary rays.

Using a piece of fresh green stem, cut thin cross sections and examine them for cell contents. Where is chlorophyl found? Determine in what parts of the section starch is present; examine particularly the cells of the cortical parenchyma, those surrounding the resin ducts, and the phloëm. Try to find crystals in the cells in the phloëm region. Look for resin; it may be tested for by tincture of alkanna. If the section is taken in the rapidly growing season, examine the cells of the cambium layer for cell contents and nuclei. State in what condition you find the cells of the xylem.

9. Cut thin radial sections of the stem. Do not try to get large sections; a narrow slice from the epidermis to the pith will show every point of the structure. Mount in Schultze's solution. Draw and locate all the parts pointed out in Fig. 135.

Under the high power study the cambium layer, starting with the narrowest cells and examining all in succession out towards the phloëm. What is the shape of the cells? Are the end partitions easily seen? Is the protoplasm abundant or scanty? Do you find a nucleus?

Describe the cells of the phloëm. Find long cells with irregularly circular patches of sieve plates on their sides; these are sieve tubes. Draw. Can you find crystals in any of the cells of the phloëm?

Examine the cells of the cortical parenchyma. What is their shape as seen in the radial section? Find resin ducts. It may be necessary to examine several sections, as all may not have passed through a resin duct. Draw some of the glandular cells with a few of the adjacent cells of the cortical parenchyma. Draw also a few of the cells of the cork layer and epidermis. Starting again with the narrowest cells of the cambium, compare the transition

to the xylem cells with the transition to the phloëm cells. Which is the more abrupt?

Study the cells of the xylem. They are called *tracheïdes*. What is their shape? Note the discoid markings on their walls. These are the bordered pits; recall their appearance as seen in the transverse section. Do you find any cell contents in the tracheïdes? Notice the medullary rays which run horizontally across the tracheïdes. Can you trace them through the cambium into the phloëm? Count the number of cells in height. Is the number constant in a given specimen? Examine radial sections of different species of Pine. Is the number of cells in the height of the medullary rays the same in different species? Follow across the tracheïdes from the inner side of one of the annual layers into the next outside layer. What changes do you notice in the size and character of the tracheïdes? Account for the difference. Do you find resin ducts in the xylem? On the border between the tracheïdes and the pith parenchyma, find tracheïdes with spiral or annular markings. Draw. Do you also find some that have

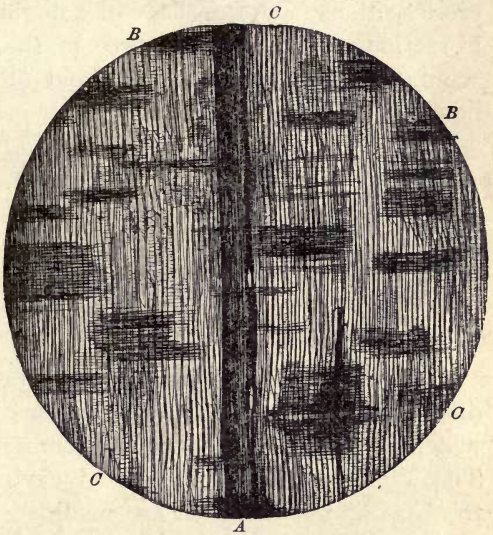

FIG. 136.—Radial section of Georgia Hard Pine, showing two of the annual layers. *A* is the boundary between the growth of the two years; *B*, *B* are medullary rays; *C*, *C*, pitted ducts. (× 35.)

both the bordered pits and the spiral markings? If so, draw.

Draw a few cells of the pith. Do you find more than one kind of cell? Do you find markings of any kind on the cell walls? Do you find any cell contents?

10. Cut tangential sections and look for the medullary rays, which will, of course, be seen in cross section. These cross sections have the shape of a double convex lens seen in section. Draw two or three of the rays, representing accurately the number of cells, and fill in the tracheïdes between.

References for Reading. — Goebel's "Classification of Plants," pp. 299–346; Vines' "Text-Book of Botany," pp. 431–489; Parker's "Elementary Biology," pp. 373–384; Strasburger and Hillhouse's "Practical Botany," pp. 298–310 f; Bessey's "Essentials of Botany," pp. 212–225; Bower's "Practical Botany," pp. 229–260; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 130–171; Boyer's "Elementary Biology," pp. 147–154; Scott's "Structural Botany," pp. 231–281.

CLASS II. **The Angiosperms.** — The Angiosperms are distinguished from the Gymnosperms by the manner in which the pollen cells and the embryo cells are borne. The ovules are borne in closed cavities, the *ovaries*, at the base of *pistils*, which are modified leaves; the pollen cells are borne in anthers raised on stamens, which are also modified leaves; both pistils and stamens may be borne in the same flower, *i.e.*, the plant may be monœcious, or they may be borne in separate flowers, *i.e.*, the plant may be diœcious; surrounding the stamens and pistils are other modified leaves forming the floral envelope, which, in normal cases, is composed of an inner circle, the corolla, usually of delicate and more or less bright-colored leaves, the petals, and an outer circle, the calyx, usually of green leaves, the sepals.

The ripened pollen grains fall by their own weight, are blown by the wind, are jerked by mechanical arrange-

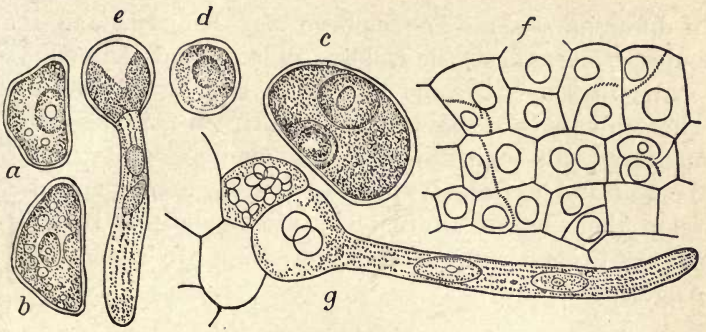

FIG. 137. — *a*, a pollen grain of the Angiosperm, *Allium fistulosum*; *b* and *c* show two stages of the development of the tube; *d* and *e* show two stages in the development of the pollen grain of *Monotropa hypopitys*; *f*, a number of pollen grains of *Platanthera bifolia* in process of division; *g*, pollen grain of *Orchis mascula* forming its tube. (After Strasburger.)

ments worked by nature, are carried by insects or birds, or in some similar manner are brought from the anthers of the same or of different flowers in contact with the viscid fluid secreted by the stigma, which forms the tip of the pistil. Excited into activity by this fluid, the pollen grain bursts its outer coat and expands its inner coat into a tube which grows down through the stigma and style until it comes in contact with the ovule, enters the micropyle of the ovule, and finds the embryo sac. The contents of the pollen grain now mingle with those of the embryo sac, and the life of a seed commences. (See Figs. 137 and 138.)

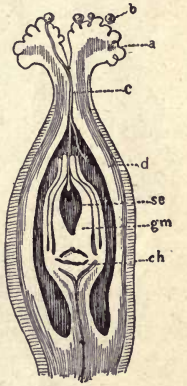

FIG. 138. — Longitudinal section of an ovary of an Angiosperm. *a*, the stigma; *b*, pollen grains; *c*, a pollen tube passing down to the egg cell, *se*. (After Thomé and Bennett.)

The matured seed incloses an embryo and more or less stored-up material, the endosperm, to nourish the embryo when it germinates. The relative proportions of embryo and endosperm vary greatly

in different seeds. The embryo may be large and the endosperm small, or the endosperm large and the embryo small; in some cases the endosperm is entirely wanting. The embryo is a rudimentary plant. When this rudimentary plant begins to grow, it sends its roots down into the soil and its leaves up into the air. Some plants develop their leaves alternately; others develop them in pairs. From these facts has arisen a division of the Angiosperms into:

SUBCLASS I. THE MONOCOTYLEDONS.
SUBCLASS II. THE DICOTYLEDONS.

SUBCLASS I. **The Monocotyledons.** — In the Monocotyledons there is only one cotyledon in the embryo. The leaves which are usually parallel-veined develop alternately. In the stems the wood is never arranged in circles, but is placed in bundles that are scattered irregularly through the entire thickness of the stem; in the more woody stems the bundles are most abundant near the circumference, forming by the interlacing ends of the fibers that compose them a tough rind or false bark to cover the stem. The parts of the flower are usually in threes; never in fives. The flowers

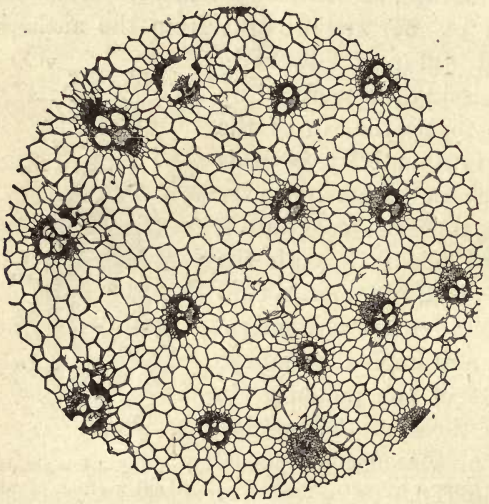

FIG. 139. — Transverse section of Sugar Cane.

range from the inconspicuous, unattractive forms borne by the grasses to the conspicuous and beautiful ones produced by the orchids.

There are about 18,000 species of Monocotyledons; these are variously arranged in groups, series, and orders by different botanists. The Monocotyledons include some of the most important economic and some of the most beautiful ornamental plants. Our present limits will permit of the study of but a single type.

INDIAN CORN. — PRACTICAL STUDIES.

1. Examine an entire plant of Indian Corn, *Zea mays*, when it is in the flower. The male flowers are borne in two-flowered spikelets in spikes at the top of the stem, constituting what is called the *tassel*. The female flowers are borne in dense spikes of many rows on short branches that grow in the axils of the leaves. Each filament of the *silk* is an elongated *style*. The pollen grains, falling or blown from the male flowers, extend their tubes through these long styles, fertilize the contents of the embryo sac at the base of the pistil, and kernels of Corn develop. Examine the leaves for their arrangement and venation. Does the plant send down a single taproot, or does it lose itself in branches? Where do the secondary roots originate? Are there roots of a still higher order?

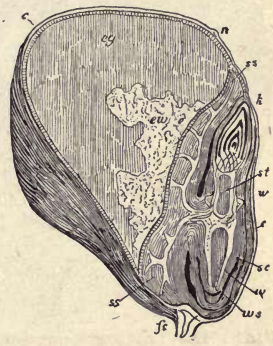

FIG. 140. — Longitudinal section of fruit of *Zea mays*. *a*, rind of the fruit; *n*, appendage of the stigma; *fs*, base of the fruit; *eg*, yellowish, firm part of the endosperm; *ew*, its white and looser part; *sc*, the scutellum of the embryo; *ss*, its tip; *e*, its epithelium; *k*, the plumule; *w* (below), the primary root; *ws*, rootsheath; *w* (above), secondary roots springing from the first internode of the primary stem, *st*. Magnified. (After Goebel.)

2. Cut through seeds of Corn in a median plane longitudinally at right angles to the broad sides. Notice the thick double-walled coating. This consists of the *pericarp* or wall of the ovary and the seed coat or developed integument of the ovule. The remains of the style will be found at the apex of the smaller end of the seed. At one side, near the smaller end of the seed, is the embryo. The embryo is separated from the endosperm by the *scutellum*, which is an arrangement for the absorption of the food for the nourishment of the embryo. The endosperm consists of two parts — a firm yellow part on the side of the seed opposite the embryo, and a less firm white part occupying the central portion and the larger end. Draw, showing all you have seen. Scrape off some of the endosperm and mount in water. Determine if starch is present. If it is, draw some of the grains. Dissect the embryos from seeds of corn that have been softened by soaking. Make out the apical bud, or *plumule*, pointed towards the large end of the seed, the *caulicle*, or *radicle*, attached to the scutellum and pointed towards the smaller end of the seed. Make longitudinal sections through the radicle and examine the rootcap and the rootsheath, or *coleorhiza*. Study the development

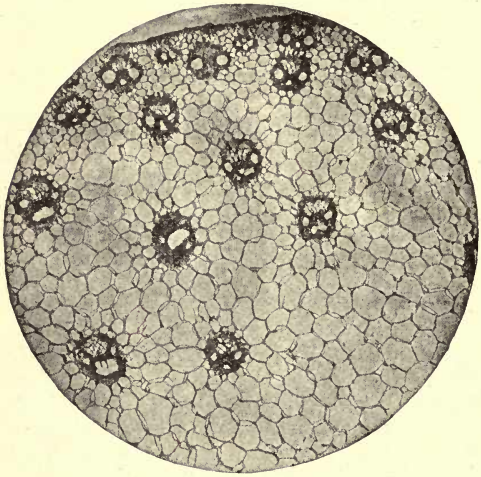

FIG. 141. — Transverse section through upper part of a Cornstalk, as seen under low power. (× 35.)

of the apical bud and radicle in seedlings from a few days to some weeks old.

3. Make a thin, median longitudinal section through the developing radicle of a seedling. Study the loosely arranged cells of the older portion of the rootcap at the very end of the root; above these are more compact and regularly arranged newer cells of the rootcap. Just above these at the apex of the root proper is the growing point of the root. Proceeding from the growing point, study the differentiation of the cells for a short distance back into the root. Notice particularly columns of broad, horizontally flattened cells. The horizontal partitions in these cells will eventually break away, and the columns of cells will be transformed into a vessel with long cylindrical segments. Find the origin of the secondary roots which, in median sections, appear as distinct circular masses at the junction between the root and the stem. Follow up the stem and locate developing leaves.

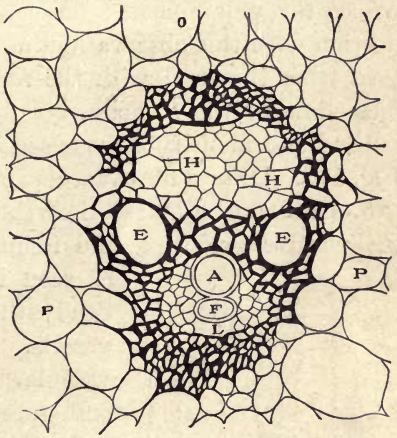

FIG. 142. — Fibrovascular bundle of Indian Corn, *Zea mays*. Transverse section, as seen under high power. *O*, *P*, *P*, cells of the ground parenchyma. The tissue represented by thick dark-walled cells is the bundle sheath; *E*, *E*, pitted vessels; *F*, an annular vessel; *A*, spiral vessel; *L*, empty space produced by the tearing apart of the tissues in consequence of rapid growth; *H*, *H*, sieve tissue constituting the bast or phloëm portions of the bundle; *E*, *E*, *A*, and *F* are the main vessels of the xylem. The lower part of the figure was situated towards the center of the stem. (× 500.)

4. Cut transverse sections of the stem. Mount in Schultze's solution. Describe the arrangement of the fibrovascular bundles. Are they definitely placed as re-

gards the outside and the center of the stem? Where are they most abundant? The space between the bundles is filled with thin-walled fundamental parenchyma. Trace this towards the outside of the stem, and notice that it changes near the epidermis into thick-walled sclerenchyma. Notice the same change as you approach the fibrovascular bundles. Is the epidermis regular or irregular? Find places in the epidermis where the section has passed through stomata; notice the guard cells. In connection with this observation, mount bits of the epidermis torn from the stem with the forceps, and study the surface view of the stomata.

Find and identify in your section all the parts shown in Fig. 142. Draw a fibrovascular bundle and label the parts.

5. Cut longitudinal sections through an internode, mount in Schultze's solution, and identify all the above tissues as seen in longitudinal sections. Study the markings on the large vessels. Trace some of the fibrovascular bundles as far as you can, and state what you observe.

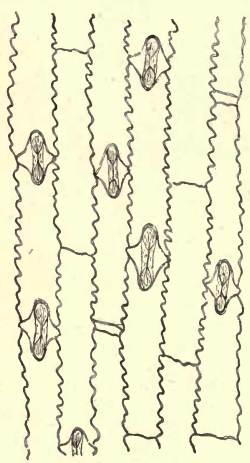

FIG. 143. — Epidermal cells and stomata of Corn.

6. Cut transverse and longitudinal sections through a node of the stem, mount in dilute caustic potash, and trace the fibrovascular bundles in their passage through the node. Notice especially the intercommunication of the bundles.

7. Mount bits of the epidermis torn from both the upper and the lower sides of the leaf. Do you find stomata on both sides? Draw a stoma under high power with its two guard cells and two subsidiary cells. Are the stomata arranged in any definite way? Note the shape of the stomata when

mounted in distilled water; then run 10 per cent solution of common salt under the cover and observe the changes.

8. Treat a piece of the leaf with Schultze's macerating mixture until it is transparent. Examine it for fibrovascular bundles, noticing particularly the fine branches that serve to connect the different bundles. How are the main bundles arranged with reference to one another? Where with reference to the bundles are the stomata situated?

9. Cut transverse sections of a well-developed leaf and also of a very young leaf of a seedling. How do the sections of the fibrovascular bundles compare in the two cases? Draw a stoma as seen in cross section.

References for Reading.— Goebel's "Classification of Plants," pp. 346–445; Vines' "Text-Book of Botany," pp. 489–569; Scott's "Structural Botany," pp. 142–197; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 172–221; Bessey's "Essentials of Botany," pp. 225–251; Boyer's "Elementary Biology," pp. 155–161.

SUBCLASS II. **The Dicotyledons.** — The characteristic that has given the name to this subclass is the pair of cotyledons in the embryo which develop simultaneously. The leaves are usually netted-veined. The wood is arranged in bundles placed in a circle, or it forms a continuous circle around the stem, though in the anomalous dicotyledons it is arranged in bundles scattered irregularly through the stem, at least in some portions of the plant. The parts of the flowers are usually in fives or fours, sometimes in threes. The flowers are sometimes inconspicuous and colorless, but are usually conspicuous and with bright-colored corollas.

This subclass includes by far the largest number of ordinary plants and trees; it exhibits the greatest variety of differentiation of stem, leaf, and flower, far surpassing in these particulars all the other subdivisions put together.

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As these exercises presuppose the previous study of the gross morphology and the analysis of a considerable number of the plants of this subclass, the practical studies will be directed to the minute anatomy of typical plants, with the particular purpose of preparing for the consideration of the physiology of the higher plants which follows.

THE DICOTYLEDONS. — PRACTICAL STUDIES.

1. Examine bits of the epidermis torn from both the upper and under surfaces of the leaves and from the young and tender stems of a number of different plants; almost any of the Dicotyledons will do: Nasturtium, Sunflower, Bean, Shepherd's Purse, Cabbage, Beech, Deutzia, and Fuchsia are good. Mount in distilled water, and, after observing the shape of the stoma, note the changes brought about by plasmolyzing with salt solution. Do you find stomata in equal numbers on both the upper and the lower sides of the leaf? Do you find them on the epidermis of the stem? Draw stomata as found on several different leaves, together with their guard cells and a few cells of the surrounding epidermal tissue. Do you find chlorophyl in the guard cells? In the epidermal cells? Do you find a nucleus and nucleolus in the guard cells? In the epidermal cells?

FIG. 144. — Stomata of Lilac leaf.

2. Place parts of leaves between pieces of pith, and cut transverse sections. Notice carefully in what parts of the section chlorophyl is found. Draw and label as many of the parts as you can by comparison with Fig. 145, which is a transverse section of a leaf of the Rubber Plant, *Ficus*

elastica. In that figure *A* is the epidermis of the upper side of the leaf. *B* is two rows of more or less rectangular cells of the *palisade parenchyma*. *C* is the *spongy parenchyma* which constitutes the greater part of the interior of the leaf. *D* is the epidermis of the under side of the leaf. *E* is a section through a fibrovascular bundle which forms the *rib* of the leaf. *F* is a *cystolith*, an aggregation formed by particles of carbonate of lime which have collected on a mass of cellulose that has formed here abnormally; it is supported by a *stalk* from the surface of the cell in which it has formed. *G* is a section through a stoma.

FIG. 145. — Portion of a cross section of a leaf of the Rubber Plant, *Ficus elastica*. *A*, epidermis of upper side of leaf; *B*, palisade parenchyma; *C*, spongy parenchyma or mesophyll; *D*, epidermis of under side of leaf; under *E* is a fibrovascular bundle; *F*, a cystolith; *G*, a stoma with cavity above it.

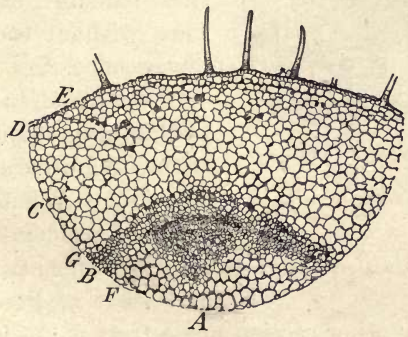


FIG. 146. — Portion of the cross section of the stem of a House Geranium, *Pelargonium*. *A*, pith parenchyma; *B*, cambium layer; *C*, cortical parenchyma; *D*, cork layer; *E*, epidermis; *F*, xylem; *G*, phloëm.

3. Study Fig. 146, which is a transverse section of the stem of a house Geranium, *Pelargonium*. It represents the *herbaceous* type of dicotyledonous stems. *E* is a single row of cells of the epidermis with projecting hairs. At *D* are several layers of cork cells. *C* is the cortical parenchyma. *G* is the phloëm or inner bark. *B* is the cambium layer and is composed of extremely delicate, radially flattened cells. *F* is the xylem or wood, which in this plant forms

a continuous though somewhat irregular ring around the stem. *A* is the pith parenchyma.

Cut transverse sections of the Geranium stem and verify the figure. In what parts do you find chlorophyl? Starch? In the cortical parenchyma find crystals. Treat with acetic acid. If the crystals are composed of carbonate of lime, they will dissolve with effervescence; if they are composed of oxalate of lime, they will not be dissolved. If the crystals are not affected, treat with hydrochloric acid. This acid dissolves the carbonate of lime with effervescence; it dissolves the oxalate of lime without effervescence.

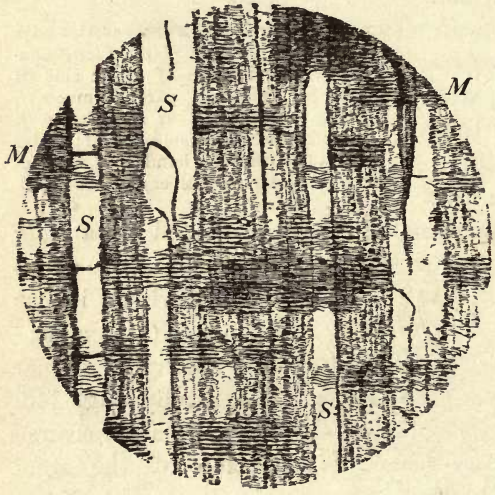


FIG. 147. — Radial section of mature Yellow Birch. *M*, *M*, medullary rays; *S*, *S*, *S*, scalariform vessels. (× 35.)

Treat a section of Geranium stem with Schultze's solution. What portions are composed of normal and what of lignified cellulose? Treat another section made from a fresh green stem with dilute iodine. In what parts do you find protoplasm? Do you find nuclei and nucleoli in any of the cells? In what parts do you find starch? Look for intercellular spaces, using high power, if necessary. Where do you find them? Under high power study the cell walls of the large vessels in the xylem; also in the phloëm. Make out three layers in the wall.

4. Cut longitudinal radial sections of the Geranium

stem. Draw and locate all the tissues shown in Fig. 146. Under high power examine the vessels of the xylem for markings on the walls. Scalariform vessels, *i.e.*, vessels whose side walls are so marked as to resemble ladders; spiral vessels, *i.e.*, vessels with a band running about them spirally; annular vessels, *i.e.*, vessels with rings of thickened tissue at intervals; and pitted vessels may be found in favorable sections. In the region of the phloëm, bast fibers are found, *i.e.*, elongated, narrow vessels with pointed ends; also sieve tubes, *i.e.*, tubes with more or less circular plates on their surfaces which serve as sieves to allow the passage of certain portions of the protoplasm from cell to cell. It may not be easy to make these out. Treat pieces of the stem with Schultze's macerating mixture, dissect them, and search for all the above vessels.

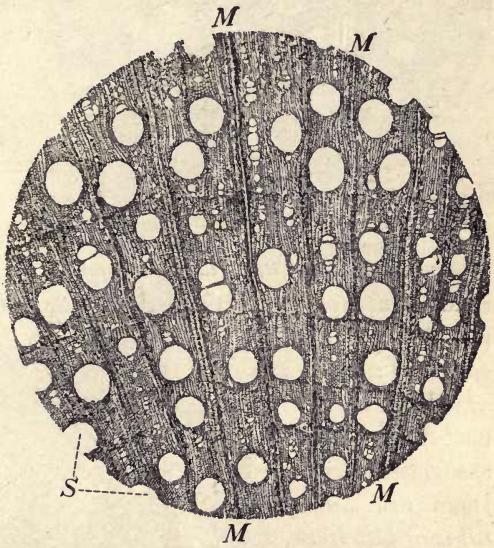


FIG. 148. — Transverse section of mature Grape stem, showing a number of annual layers, large and small vessels, and medullary rays. (× 35.)

5. Cut a transverse section of the Milkweed stem. Draw it under low power and label all the parts you can make out by comparing it with Fig. 146. It will be seen that this stem corresponds very well with the Geranium stem in structure. There is a tendency to divide

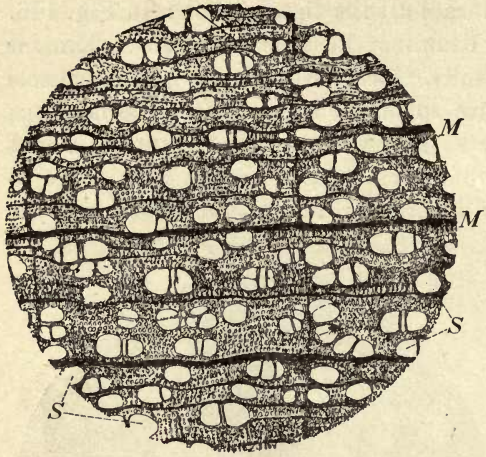


FIG. 149.—Transverse section of mature Yellow Birch, showing part of three annual layers. *M*, *M*, medullary rays; *S*, *S*, scalariform vessels.

the ring of xylem into four parts, or bundles, which are, however, connected by the cambium layer which forms a complete ring. The cambium in the bundles is called *fascicular* cambium; that between the bundles, *interfascicular* cambium. On the inner side of the cortical parenchyma, and just outside the inner phloëm, are irregular patches of denser tissue; these are bundles of bast fibers, and associated with them are *latex tubes* or *laticiferous vessels*. The latex tubes are not, however, confined to the bundles of bast fibers, but spread as a very delicate network throughout nearly all the tissues of the stem.

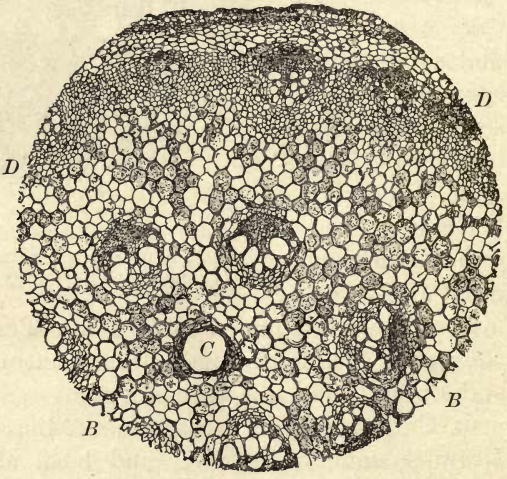


FIG. 150.—Transverse section of stem of *Piper futokadsura*. *D*, *D*, the normal ring of fibrovascular bundles; *B*, *B*, the second ring of bundles; *C*, the hollow center of the stem. Anomalous. (× 35.)

Cut longitudinal radial sections of the Milkweed stem, and study the scalariform, spiral, pitted, and annular vessels of the xylem, and the bast fibers and sieve tubes of the phloëm. Also dissect a piece of the stem that has been treated with Schultze's macerating mixture, and look for these vessels.

6. Cut a transverse section of a well-developed Sunflower stem. Draw it under low power, and locate all the parts you can by reference to Fig. 151. Notice that the vascular tissues are here separated into quite a number of distinct fibrovascular bundles connected by delicate interfascicular cambium. Each bundle develops on the inner side into the large and small vessels of the wood; on the outside, into sieve tubes and bast.

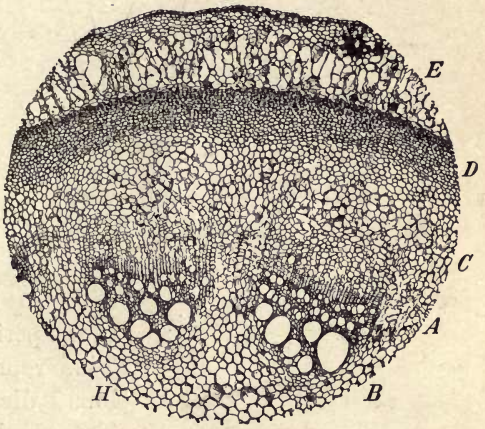


FIG. 151. — Transverse section of the stem of *Aristolochia latifolia*. *A*, the cambium layer; *B*, the xylem; *H*, pith parenchyma; *E*, the cortex or bark; *D*, inner bark or phloëm; *C*, cortical parenchyma.

Cut longitudinal radial sections of the Sunflower stem, and study under high power the scalariform, spiral, pitted, and annular vessels of the xylem, and the bast fibers and sieve tubes of the phloëm.

7. Cut and study in the manner indicated in the preceding exercises transverse and longitudinal sections of other herbaceous Dicotyledons. Artichoke, Blackberry, Raspberry, Clematis, Evening Primrose, Pigweed, and all other similar stems are good.

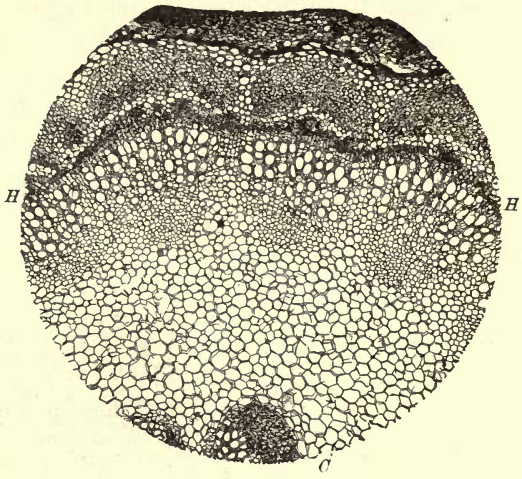


FIG. 152. — Transverse section of the petiole of Horse-chestnut. *H*, *H*, the normal ring of fibrovascular bundles; *C*, *C*, the centrally located bundles which branch into the subdivisions of the leaf. (× 35.)

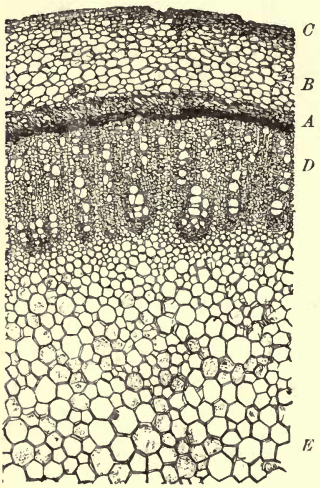


FIG. 153. — Part of transverse section of first year's growth of stem of Basswood. (× 35.)

8. Cut transverse sections of the petiole of Horse-radish. This represents the anomalous dicotyledonous type. The wood is not arranged in a circle, nor even in bundles arranged in a circle, but the fibrovascular bundles are scattered about without definite order. For another example of the same type cut transverse sections of the petiole of Plantain.

9. Study Fig. 153, which is a transverse section of the stem of Basswood. It represents the *arboreous* type of

the Dicotyledons. The section from which this figure was photographed was cut late in the season, after the activity of the cambium had ceased. It shows the growth of one season. The inner side of the dark ring at *A* represents the position of the cambium layer; the outer portion of the same ring is the phloëm, or bast. *B* is the parenchyma of the cortex. The outer row of cells at *C* is the epidermis. *D* is the xylem; in it the large openings are principally scalariform vessels; the fibrovascular bundles, which form a complete ring around the stem, are much crowded together, and the compressed parenchyma between them already begins to assume the form of medullary rays. *E* is the pith parenchyma.

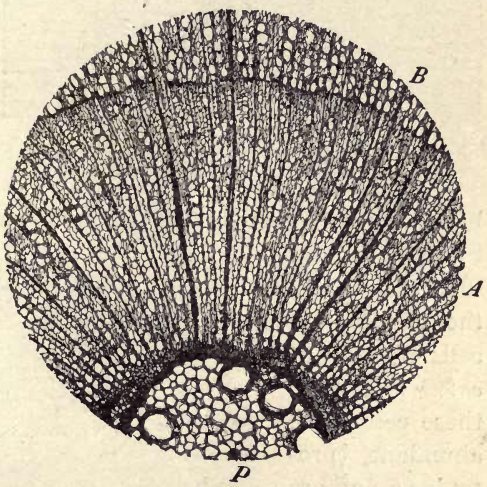


FIG. 154. — Transverse section of older Basswood stem. *A*, wood of first annual ring; *B*, part of second annual ring; *P*, pith parenchyma.

Figure 154 shows a portion of a transverse section of an older stem of Basswood taken near the pith. *P* is the pith parenchyma. *A* is the first annual ring of the xylem. *B* is a part of the second annual layer. Well-developed medullary rays run through *A* and *B*. *A* shows well the large vessels that develop in the first growth and the small vessels that are formed in the latter part of the season

10. Cut transverse, radial, and tangential sections of other arboreous stems. By reference to Figs. 147 and 155 identify the various tissues. Maple, Birch, Elder, Elm, Cherry, Apple, and Pear stems are favorable specimens. Draw a portion of each section, indicating particularly any differences you find in the same tissue in the different stems.

FIG. 155. — Tangential section of Mountain Ash, showing end views of the medullary rays. (× 35.)

11. Imbed in paraffin or celloidin apical buds of Lilac, Artichoke, or Sunflower, and cut longitudinal median sections. Study the thin-walled cells of the *apical meristem;* these cells have abundant protoplasm and are in an actively dividing condition. Near the apex is the growing point. Trace the cells of the apical meristem back into the stem, and notice their differentiation into the

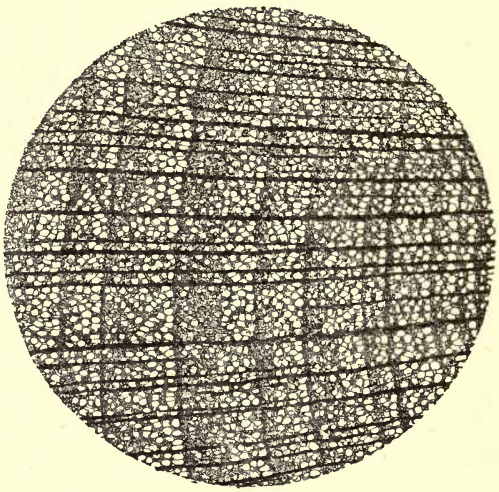


FIG. 156. — Transverse section of Mountain Ash, showing a number of annual layers, medullary rays, the large vessels formed in spring growth, and the small vessels of late season growth. The right side of the figure was situated towards the center of the stem. (× 35.)

various tissues of the stem that have already been studied. Notice also, particularly, that the meristematic cells are identical in their nature and function with those of the cambium layer.

12. Cut transverse, radial, and tangential sections of the roots of the plants that have been used in Numbers 3 to 11, using both young and old portions of the roots. Are the fibrovascular bundles continued into the roots? If so, do you find that they here exist in a modified form? Compare each section with the corresponding section of the stem of the same plant. Do you find chlorophyl? Do you find protoplasm in the cells of the root? If so, in what parts? Treat with iodine. Do you find a nucleus and nucleolus? Starch?

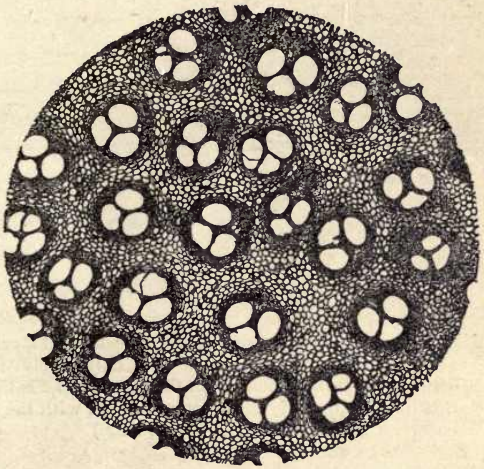
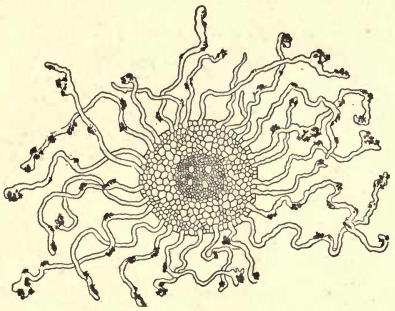


FIG. 157.—Bristly Sarsaparilla, showing the anomalous arrangement of the fibrovascular bundles. (× 35.)

13. Germinate beans of some large variety until the radicle is enlarged and is in an actively growing condition. Imbed radicles in paraffin or celloidin, and cut longitudinal median sections. Make out the rootcap. Just back of this and near the apex of the root proper find the *growing point*. Notice the thin-walled cells of the *meristem* that have resulted from recent divisions of the cells at the growing point. Trace these cells up

into the radicle, and notice that they are continuous with the cambium.

14. Examine the roots of the plants that have been studied for root hairs. Do you find them on the young or the old parts? How far from the tips of the roots are they located? These hairs are the organs for the absorp-



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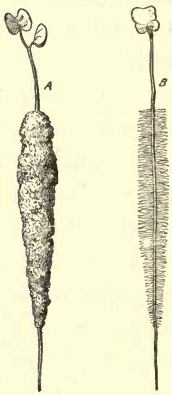


159

FIG. 158. — Cross section of a root. The typical structure of roots is shown; also the manner in which the root hairs apply themselves to particles of dirt to obtain nutriment from them. (After Franke.)

FIG. 159. — Seedling of White Mustard. *A*, with the dirt clinging to the root hairs; *B*, after washing. (After Sachs.)

tion of the plant's food from the soil. In most cases they excrete an acid cell sap which dissolves the solid mineral constituents of the soil and prepares them for entrance into the root hair by osmosis.

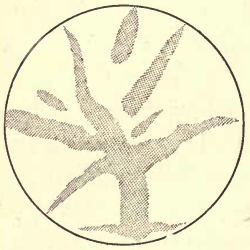


FIG. 160. — Polished marble corroded by the action of the sap from root hairs. (After Detmer.)

Place a piece of highly polished marble in a box, cover it with two or three inches of clean sand, and plant Beans and Peas in the sand. Keep well watered and under favorable conditions until the plants have attained considerable size. Then take out the marble and ex-

amine it by reflected light for marks made by the corroding action of the sap from the root hairs. Touch the root hairs of some of the plants with blue litmus paper. The change of color from blue to red shows the presence of an acid.

15. Show that carbon dioxide is given off by growing plants.

a. Soak Beans or Peas in water over night, place them in a moderately warm place on wet paper during the day, and at night fill a 500 c.c. flask one third full of them. Stopper the flask and keep it in a warm room over night. In the morning lower a lighted splinter into the flask. The carbon dioxide that has been developed by the germinating seeds puts out the flame.

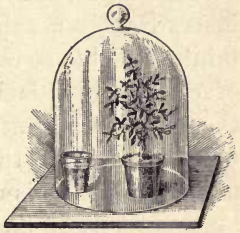


FIG. 161. — Arrangement of apparatus to show that carbon dioxide is given off by a growing plant. (After Mangin.)

b. Place a healthy growing plant under a bell jar over night with a beaker of clear lime water. In the morning notice that the union of the carbon dioxide given off by the plant with the lime water has formed a film or cloudiness of carbonate of lime.

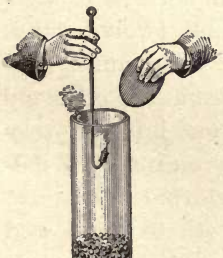


FIG. 162.—Arrangement of apparatus to show that carbon dioxide is given off by growing seedlings. (After Sachs.)

16. Show that carbon dioxide is necessary for growing plants.

a. Boil some water to expel the carbon dioxide contained in it. After it has cooled, cultivate in it any plant that thrives wholly submerged in water. The experiment is most successful when the vessel in which the culture is made can be closed by a stopper bearing a bulb tube containing caustic potash or caustic soda

through which fresh air is admitted deprived of carbon dioxide. Recall similar experiments performed with Spirogyra and other Algæ.

b. Stand cylinders, bearing healthy cultures of seedlings in Sachs' food solution, in a shallow dish of water. Cover with a tubulated bell jar, so placed that the water in the shallow dish seals the bottom. In the tubulature insert tightly a rubber stopper bearing a bulb tube containing caustic soda or caustic potash. Fresh air deprived of carbon dioxide is admitted through the tube. Place the whole in strong sunlight. Examine daily. Does the plant continue to thrive? More than one half of the solid matter of plants is carbon. Plants thrive and attain their best maturity in Sachs' solution which contains no carbon in any form. They must therefore obtain it from the air.

17. Show that oxygen is necessary for growing plants.

a. Fill two ordinary chemical retorts, neck and all, with water that has been boiled to expel the contained gases. Put a few Peas or Beans in the bottom of each retort, and stand the retorts, neck down, in a vessel of mercury. Let them stand twelve hours to soften the seeds. Then run hydrogen gas into one from an ordinary hydrogen apparatus, and into the other blow ordinary air by means of a bellows, inclining the retorts to drain out the water. Allow both to stand, and observe that the seeds in the retort containing hydrogen do not germinate, while those in the retort containing air develop.

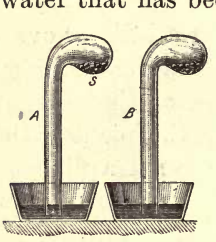


FIG. 163.—Tubes for the study of seedlings when deprived of oxygen. (After Detmer.)

b. On the bottom of a 500 c.c. flask place on a wet filter paper a layer of Barley that has been soaked in water twelve hours, and stand a test tube containing a strong solution of caustic potash in the flask. Stopper

the flask with a rubber stopper having a bent tube. Place the hands on the flask to warm it and drive out some of the air, and then support it with the outer end of the bent tube dipping under mercury. As the Barley germinates, the carbon dioxide given off is absorbed by the caustic potash solution. The oxygen of the air in the flask is used by the plant, as is evidenced by the mercury which rises to offset the tendency to form a vacuum in the apparatus.

18. Show that heat is produced by germinating seeds. Fit two 500 c.c. flasks with stoppers bearing thermometers. Fill one of the flasks one third full of Peas that have been soaked in water twelve hours, letting the bulb of the thermometer be well covered with Peas. Note the reading of the two thermometers. Set both flasks in same conditions, and after some hours take the readings of the thermometers again. Has heat been produced by the germinating seeds?

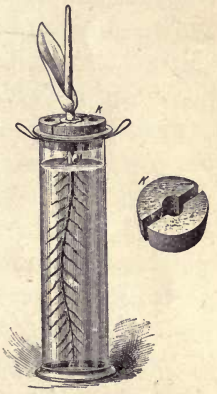


FIG. 164. — Cylinder for the cultivation of seedlings in different solutions. (After Hansen.)

19. Study the food materials necessary for the healthy growth of plants. Germinate seeds of Peas, Beans, and Buckwheat on clean sand until they are well started. Transfer some to pots of ordinary loam. Make cultures of others as follows: Fit large test tubes or small cylinders with corks that have been split vertically and the centers somewhat hollowed to allow room for the seedling. Secure a seedling in each cork by means of asbestos fiber so that its root will dip in the solution to be placed in the cylinder. In one cylinder place distilled water; in another ordinary well or river water; in several others Sachs' solution for green plants,

FIG. 165. — Apparatus showing arrangements for the cultures in Number 19. (From Vines, after Nobbe.)

omitting in succession one ingredient of the solution. Place in the sunlight and under favorable conditions of warmth, and renew the solutions about once a week. From a comparison of the results, what elements do you think are necessary for the healthy growth of green plants. Renew the solutions again, adding the missing ingredients. What is the effect on the plants? Compare the root hairs in each case with those formed on plants growing in the soil in the pots. State what you notice. Do the plants grown in watery cultures need as abundant root hairs as those grown in soil?

20. Germinate some Beans or Peas until the radicles are half an inch long. Grind them to a pulp with water. Test a portion for sugar as follows: Add a little caustic soda solution and then a little copper sulphate solution. This treatment will give a reddish brown color, if sugar is present. Do the germinating seeds contain sugar? Test another portion of the solution for starch with iodine solution. Do the germinating seeds contain starch? Test another portion of the solution for proteids by adding a few drops of a solution made by dissolving a small drop of mercury in nitric acid. Acid enough must be used to dissolve the mercury entirely. This is known as Millon's reagent; it gives a red color with proteinaceous substances. Do the germinating seeds contain proteinaceous substances?

21. How do the food materials get into the plants? Cover the mouths of four thistle tubes with bladder. Fill one of the tubes held mouth down with water containing all the sugar it will dissolve to a point about one centimeter above the bulb. Stand it mouth down in a beaker of water so that the water in the beaker and the sugar solution in the tube are at the same level. Fill another tube similarly with water, to which a quantity of starch has been added, and arrange it in a beaker of water in the

same way. Fill a third tube with water and starch after boiling. Fill a fourth tube with boiled starch and water, to which a small amount of diastase of malt has been added. After some time observe whether water has entered the thistle tubes by osmosis through the diaphragm, and risen in their stems.

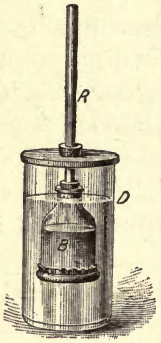


FIG. 166. — Apparatus for the study of osmosis. (After Müller.)

Test a little of the original solution for sugar. Test the water in the first beaker for sugar. Has sugar passed through the bladder into the water? Also taste the water.

Test a little of the original starch solution with iodine solution, after diluting with ten times the volume of water. The characteristic blue color is obtained. Test the water in the beaker for starch. Do you find it? Test the water in the second, third, and fourth beakers for starch in the same way. Has starch passed through the bladder into the water? Test the water in these three beakers for sugar. Do you find it in any case? What is your conclusion from these tests?

The experiment may be varied by using, instead of the thistle tubes, short pieces of glass tubing with the ends covered with bladder. Each piece of tubing so arranged represents very well a plant cell immersed in water.

FIG. 167. — Imitation plant cell for the study of osmosis. (After Oels.)

Substances that will pass through membranes by osmosis are called *crystalloids;* substances that will not so pass are called *colloids*.

22. Prove that some diastatic ferment is present in germinating seeds. Germinate some Barley until it is

well started, grind to a pulp, mix with water, and let it stand one or two hours, filter, and add some thin boiled starch. Test for starch with iodine at intervals of half an hour. The diminishing intensity of the blue color shows that the starch is diminishing in quantity; it finally wholly disappears. Test for sugar. Is it found? What do you conclude as to the presence of a diastatic ferment in the germinating Barley?

23. Prove that the starch in a plant is a reserve food to feed the plant at times when the formation of new food materials is impossible; also that a plant can convert sugar into starch. Keep a Geranium or Nasturtium in the dark for a day or two. Test bits of the leaf for starch by dissolving out the chlorophyl with hot alcohol and applying iodine solution. After a time the failure to obtain the blue color proves that no new starch is being formed in the absence of the sunlight, and that the starch previously formed has been used up or transferred to other parts of the plant. Now cut leaves from the plant and place them with the cut ends in a beaker of sugar solution in the dark. Test bits of these leaves daily, after two or three days, for starch until you find that some has been formed.

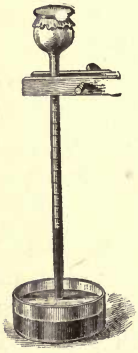
24. How do the nutrient fluids get to the portions of the plants that are raised in the air?

a. Arrange capillary glass tubes, *i.e.*, tubes of very small bore, so that their ends dip into water. Arrange in the same way a lamp wick and a piece of Pine wood. The water can rise a certain height by capillary attraction. It can in no case rise so as to flow over the top of the tube unless the top is in contact with some other object. Will capillarity account for the rise of water in large plants?

b. Cut off a Geranium plant a short distance above the soil, and attach to the stump by means of a piece of rubber

tubing a glass tube arranged vertically. See that the joints are perfectly tight. The sap soon rises into the glass tube. Observe its height from day to day. It is forced up by what is known as root pressure. This experiment is most successful in the spring.

c. Fill a thistle tube, having a bladder diaphragm over its mouth, with water, and stand it, mouth up, with the lower end of the stem dipping into mercury. Observe



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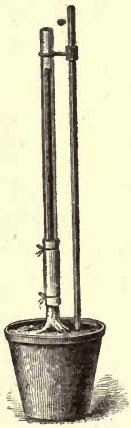

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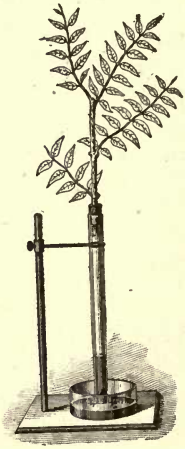


170

FIG. 168. — Apparatus to show the lifting effect of evaporation through a membrane. (After Oels.)

FIG. 169. — Apparatus to show the effect of root pressure. (After Detmer.)

FIG. 170. — Apparatus to show the lifting effect of transpiration from the leaves. (After Detmer.)

that the water evaporates through the membrane and the mercury rises in the stem of the tube. Keep it under observation for some days.

d. Arrange a glass tube so that one end dips in mercury. Fill the tube with water. Fasten the top of the Geranium used in *b* by means of a rubber stopper so that its end will dip in water, making the joints air tight. Because of the transpiration of the water from the leaves,

the volume of the water in the tube is diminished, and the mercury rises into the tube.

25. Show that the presence of sunlight is necessary for the healthy development of plants.

a. Place plants that are growing healthily in a dark room. Keep all other conditions favorable. Examine at intervals for several weeks. Do they continue healthy? Do they grow more or less rapidly than in the light?

b. Weigh each of a number of Peas and Beans. Germinate them, using Sachs' food solution. After they are well started keep one half in the sunlight and the other half in the dark, all other conditions being alike and favorable. After three or four weeks remove the seedlings, rinse in water, and dry for a week at the ordinary temperature and protected from dust. How do the weights compare with the original weights of the seeds? What conclusion do you draw from the experiment?

c. Cut transverse sections of leaves that grow in the bright sunlight and of those that grow in the dense shade of the interior of a thickly leaved tree. Leaves of Beech are good. Compare the palisade parenchyma produced under the different conditions. What conclusion do you draw?

26. Study the movement of the nutrient fluids.

a. Girdle a young tree by removing the bark and the youngest layer of wood. The tree continues to live for some months. This proves that the nutrient fluids ascend in the older wood, and not in the bark portions. The tree dies before the second season. This proves that the nutrient fluids, elaborated into foods in the leaves and other portions of the plant, could not descend to nourish the roots, and there to be stored up for future growth of the plant. These fluids must therefore descend in the bark portions of the plant.

b. Place the cut end of a Geranium stem in a solution

of eosin in water. After a time remove, rinse in water, and make transverse cuts at gradually increasing distances from the lower end. In what tissues did the colored solution rise the highest? Make also longitudinal sections of a piece of stem similarly treated.

c. Remove a zone of bark and the youngest layer of wood from a Willow branch, leaving the bark intact for about two inches on the lower end. Place in water so that the peeled portion and about an inch of the bark above it are wholly covered with water. The branch grows and forms new roots from the bark above, but none from the bark below the peeled portion. This proves that the nutrient materials for the roots descend in the bark portions.

27. Plants do work.

a. Plants not only raise their aërial portions into the air against the force of gravity, and carry up food material from the soil, but they can carry up weights attached to the branches. The roots force their way downward into the soil in some cases against great resistance. The splitting and moving heavy stones by the roots of trees are familiar examples.

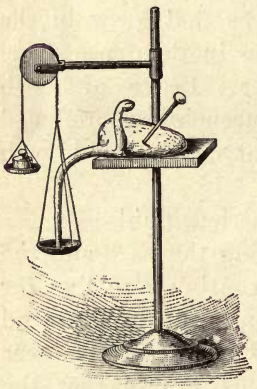


FIG. 171.—Arrangement of appafatus for measuring the work done by the radicle of a seedling. (After Mangin.)

b. Counterpoise a delicate beam balance, using damp sand for the purpose in both pans. By the side of one pan support in the horizontal position a Bean seedling with a radicle half an inch long, with the radicle lying lightly but not pressing upon the pan of the balance. The Bean itself should rest in a drop of water, and the whole should be

placed in strong sunlight with favorable conditions of heat. In two or three hours the radicle obeying geotropism pushes the pan of the balance down.

28. Study geotropism. Germinate Beans until the radicles are half an inch long. Pin the Beans to large corks, and insert the corks in bottles nearly full of water so that the radicles are placed horizontally. Tip the bottles so as to wet the seedlings. Place in strong sunlight. After a time notice that the end of the radicle turns downward. It is positively geotropic. The plumule tends to turn upward. It is negatively geotropic. Continue the study of positive and negative geotropism, using young plants of Onions, Tulips, and Hyacinths, fixing them in horizontal positions after the growth is well started, and supplying suitable conditions for nutriment, light, and heat. Also sow Peas or Beans in a hanging sponge; keep well watered. After the seedlings are well started, turn the sponge upside down and study the changes in the directions of growth of the stems and roots.

FIG. 172. — Seedling of Bean, showing positive geotropism. *G* is a bell jar standing in an open dish, *B*, which contains water; *S*, the seedling. (After Detmer.)

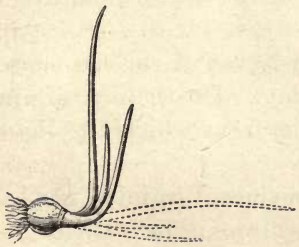


FIG. 173. — Young Onion plant, showing negative geotropism. (After Frank.)

29. Study heliotropism.

a. Grow seedlings of Canary Grass or Beans in a wet sponge hanging in a box painted black on the inside. The box should have a removable, light tight cover, and, on the side toward a window, a hole which is closed with a cork until the seedlings are well started. The cork is

then removed. After three or four hours, remove the top, and observe that the plants have turned towards the light. They are positively heliotropic.

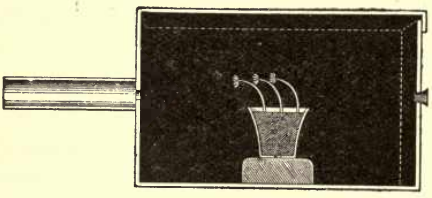


FIG. 174. — Dark box for experiments in heliotropism. (After Schleichert.)

b. Grow seedlings of Mustard in damp sawdust until they are well started. Remove them from the sawdust, and support them by means of bent wire, carrying thin pieces of cork, just above the surface of water in a beaker. Holes should be made in the cork, and each seedling should be placed with its radicle pointing downwards in the hole, and then secured with asbestos fiber. Set the beaker in a box arranged as in *a*. After several hours of exposure to the light admitted by the hole in the side of the box, examine and record your observations.

c. Observe the positions of the leaves of various house plants at different hours of the day. Do their positions bear any relation to the direction from which the light comes?

d. Observe the tendrils of Grapevines, Virginia Creeper, and other climbing plants. They are negatively heliotropic, and turn away from the sun towards the supporting wall.

30. Study hydrotropism. Provide a wooden box eight or ten inches long and two inches deep, and without a bottom. Tack mosquito netting over the bottom. Spread on this a thin layer of sawdust, and place Beans and Peas that have been soaked in water for twelve hours on this. Fill the box with sawdust, and hang it at an angle of 40° or 50° with the horizon. Keep the sawdust damp by an occasional spraying and in an atmosphere that is neither

too dry nor too damp. Sachs, the originator of the experiment, recommends a dark closet, the floor of which is occasionally watered. If the conditions are right, the radicles, as they emerge from the lower part of the box, will not obey geotropism, but will grow close to the damp sawdust. In an atmosphere that is too moist, the radicles obey geotropism. In obedience to the fact illustrated by this experiment, plants send their roots towards sources of moisture in the earth. The penetration of wells by the roots of trees is a well-known source for the contamination of well water.

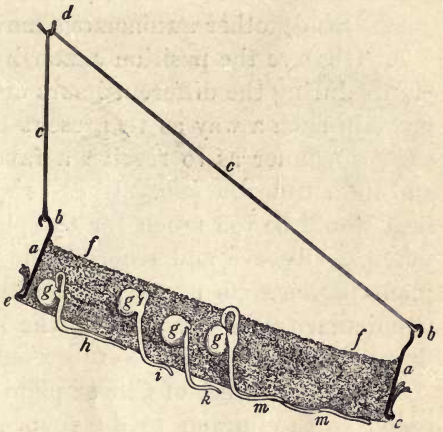


FIG. 175.— Apparatus to show hydrotropism. (After Sachs.)

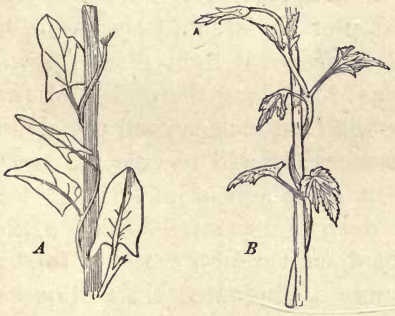


FIG. 176.— *A*, part of a plant of *Convolvulus arvensis*; *B*, part of a Hop vine. (After Edmonds.)

31. Study twining movements.

a. Raise Beans in a flower pot. Set a stake in the pot. Do the seedlings move in the direction of the stake, or must they be placed in contact with it before they begin to twine around it? Determine how long it takes for the tip to make a complete revolution around the stake.

b. Make similar observations on the Hop and the Honeysuckle. Do the Bean, Hop, and Honeysuckle twine about the stake in the same direction?

32. Study other autonomous movements of plants.

a. Observe the position taken by the leaves of various plants during the different hours of the day. The leaves move in such a way as to present their upper surfaces in such a manner as to receive a favorable amount of heat and light from the sun. In cases where the full light and heat would be too much for the plant, other positions are taken. Observe and record some instances in which the plant presents its upper surface in a position nearly perpendicular to the direction of the sun's rays through the day.

b. Place a clump of Clover plants together with considerable earth clinging to the roots in a flower pot, or use seedling Cabbages or Sunflowers. Study circumnutation by Darwin's method. Insert a small stick firmly in a vertical position, and, by means of pieces of gummed paper so applied that they will not injure the plant, fasten the petiole of a healthy leaf to the stick, leaving the blade of the leaf projecting above the top of the stick. By means of shellac, dissolved in alcohol, fasten a light glass thread, made by drawing out a glass rod, along the midrib of the leaf, and allow it to project half an inch beyond the tip of the leaf. Place the plant where it will receive the light from above. A convenient arrangement is to place the plant in the bottom of a deep box painted black on the inside, and reflect the light down through the open top by means of a mirror. Arrange a graduated scale opposite the glass index. Observe the position of the index at different hours of the day and record the results.

33. Sleep of plants.

a. Observe the position of the Clover, Wistaria, Wood Sorrel (*Oxalis acetosella*), young plants of other species

of Oxalis, Impatiens, or Beans during the daylight and again as darkness comes on.

b. Observe the flowers of Morning Glory, Mayweed (*Maruta cotula*, D. C.) of the cultivated Daisy (*Bellis perennis*) during the day and again late in the afternoon.

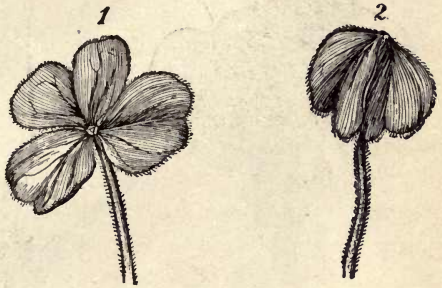


FIG. 177. — Leaf of *Oxalis carnea*. 1, the ordinary day position; 2, night position. (After Sachs.)

c. In the earlier part of the day place an Oxalis growing in a pot in a large box painted black on the inside and from which all light is excluded. In two or three hours examine the position of the leaves. Make similar observations by inverting a box over Clover plants growing naturally out of doors. Make the box light tight all around.

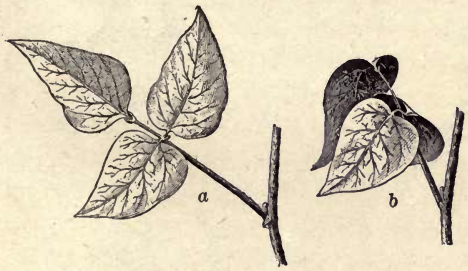


FIG. 178. — Leaves of a Bean. *a*, the day position; *b*, the night position. (After Detmer.)

This change of position is brought about by variations in the growth of the cells on the upper and under sides. In cases where the movements are most distinct, this variation in growth occurs in a distinct swelling at the base of the petiole known as a *pulvinus*. Sections through the pulvinus often show a distinct difference in the size of the cells.

The sleep movements of plants are believed to be pro-

visions of nature to protect from too great radiation of heat during the cool hours of the night. Darwin has shown that leaves which are prevented from taking the positions natural to them are killed or seriously injured on chilly nights, while other leaves on the same plant do not suffer. This is but a continuation of the provision already noted under Number 32, whereby nature provides that plants shall receive or retain an amount of heat suited to their individual needs.

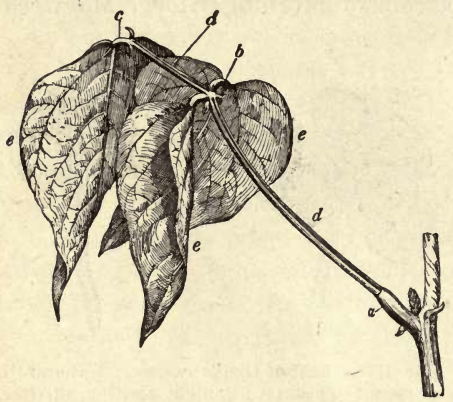
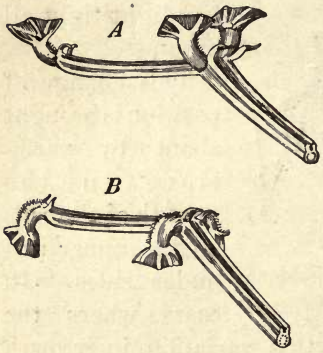


FIG. 179. — Leaf of the Scarlet Runner, *Phaseolus multiflora*, in the sleep position. (After Sachs.)



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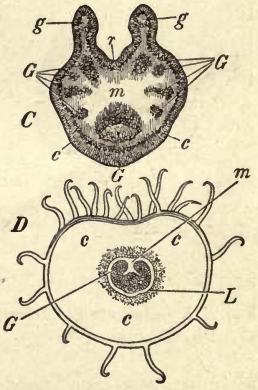


181

FIG. 180. — Upper portion of the leaf stalk of the Scarlet Runner, showing the motile organs of the leaflet. *A*, day position; *B*, night position. (After Sachs.)

FIG. 181. — *C*, cross section through the rigid portion of the stem of Scarlet Runner; *D*, cross section through a motile organ. (After Sachs.)

34. Study movements due to irritation.

a. Shake a flower pot in which a Sensitive Plant (*Mimosa pudica*) is growing, and watch the movements of the

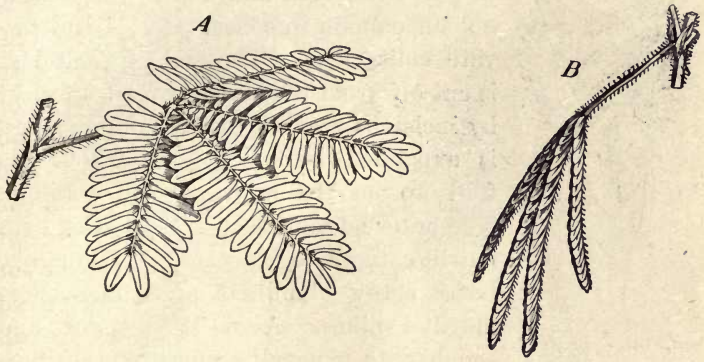


FIG. 182. — Leaf of the Sensitive Plant, *Mimosa pudica*. *A*, the ordinary day position; *B*, after irritation. (After Duchartre.)

petioles, the secondary petioles, and the leaflets. Note the time that elapses before the leaves return to their former positions. Repeat the shaking. Does the plant respond to the irritation with the same promptness? Strike a sharp blow with a pencil on a pair of terminal leaflets. Observe that the stimulus travels to the other leaflets of the same leaf, and perhaps even to other leaves. Touch in succession with the sharp point of a pencil the upper and the under sides of the pulvinus. Does the plant respond in either case? This plant may be grown from seed.

FIG. 183. — Oxalis with leaves in sleep position. (After Hansen.)

b. Shake vigorously a flower pot containing plants of *Oxalis acetosella* or *Oxalis stricta*. It may be necessary to repeat. Vigorous irritation causes the leaflets to sink

and take their sleep positions. Rub the under side of the pulvinus for some time. Note the effect on the leaflets.

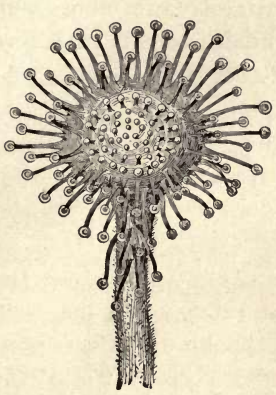
FIG. 184. — Leaf of Venus's Flytrap, *Dionæa*. (After Kerner.)

c. Venus' Flytrap, which grows native in parts of North and South Carolina, is not uncommon in conservatories and private collections. The end of each leaf is cut off from the lower part of the leaf by incisions reaching to the midrib, and is expanded into two lobes which can fold up on the midrib as on a hinge. The outer edge of each lobe bristles with hairlike teeth, or tentacles. Each lobe bears many glandular areas and three hairlike spikes. Avoid these spikes, and touch with a pencil point any other portions of the lobes, or marginal hairs. Does the leaf show any movement? Touch the spikes. What is the result? Touch the hinges. What is the result? Observe how long a time elapses before the leaf resumes its former position. Place a small insect in contact with one of the spikes. Keep the plant under observation long enough to see what happens.

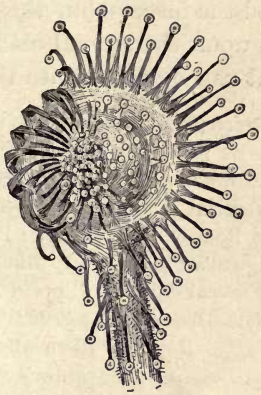
FIG. 185. — *Drosera rotundifolia*. Entire plant. (After Bentham.)

d. The Sundew (*Drosera rotundifolia*) is common, growing half buried in masses of Sphagnum Moss in bogs. Each individual plant consists of several round leaves of a reddish color, which lie prostrate, and an upright flower stalk with whitish flowers. Each leaf is borne at the end of a somewhat long petiole. The petioles and the flower stalk originate at a common center. Each leaf bears on its surface, and especially around the circumference, hair-

like tentacles. These are not true hairs. Each is penetrated by a branch from the fibrovascular system of the leaf. At the tip of each is a minute gland which secretes a



186



187

FIG. 186. — Leaf of *Drosera rotundifolia* with its tentacles expanded. (After Darwin.)

FIG. 187. — *Drosera rotundifolia* with the tentacles of the left side contracted and inclosing a bit of meat. (After Darwin.)

thick, sticky liquid. Touch these tentacles with bits of meat or with insects. What is the result? Repeat, using inorganic substances. Is the result the same as before? Place bits of meat on the inner part of the leaf, but not touching the tentacles. Keep under observation for ten or fifteen minutes.

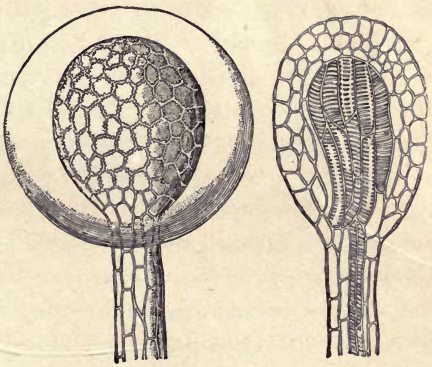


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FIG. 188. — 1, the head of one of the tentacles of *Drosera rotundifolia*, with a drop of the viscid secretion surrounding it; 2, a section through the head, showing the structure. Highly magnified. (After Darwin.)

The viscid secretions of the Sundew and Venus' Fly-trap, as is the case with the corresponding secretion of other insectivorous plants, serve not merely to catch and hold the insects, but they contain digestive ferments which act upon the animal matter and break it down into forms that can be taken into the plant to serve as food.

References for Reading. — Goebel's "Outlines of Classification," pp. 445–472; Vines' "Text-Book of Botany," pp. 570–783; Scott's "Structural Botany," pp. 12–141; H. Marshall Ward's "The Oak"; Bower's "Practical Botany," pp. 54–228; Strasburger and Hillhouse's "Practical Botany," pp. 311–372; Dodge's "Practical Biology," pp. 336–377; Bidgood's "Elementary Biology," pp. 145–190; Huxley and Martin's "Practical Biology," pp. 460–481; Arthur, Barnes, and Coulter's "Plant Dissection," pp. 222–242; Bessey's "Essentials of Botany," pp. 251–278; Boyer's "Elementary Biology," pp. 162–166; Gray's "Structural Botany"; Carpenter's "The Microscope," pp. 609–650; Darwin's "Power of Movement in Plants"; Darwin and Acton's "Physiology of Plants"; MacDougal's "Plant Physiology"; Goodale's "Physiological Botany"; Geddes' "Chapters in Modern Botany"; Strasburger, Noll, Schenck, and Schimper's "Lehrbuch der Botanik," pp. 131–260, 372–520.

APPENDIX.

1. MATERIAL FOR LABORATORY USE.

The labor involved in conducting a class in the practical laboratory study of Botany is much diminished by a little care and forethought. Material for study cannot generally be found in nature when wanted in sufficient abundance and variety for satisfactory work; it should be sought at the proper seasons of the year and should be preserved for future use. As a rule, the cheapest and best preservative is formalin (formic aldehyde); alcohol of from 70 to 90 per cent strength may be used. The life histories of plants cannot be fully studied at any time during the year without the help of such material. In many cases it costs little more time and trouble, when plants in suitable condition have been found, to secure a supply sufficient for two or three years. This stock should be used to supplement the plants that can be obtained in the fresh state at the time the study is made.

The lower microscopic forms should be cultivated in the laboratory. The process is very simple, and a reasonable amount of care will furnish abundant material. The only apparatus necessary is a supply of jars or large bottles — the larger the better, but small ones will do — and plates of ground glass or ordinary window glass to cover them and prevent too rapid evaporation of the water. The mode of procedure is to place in these jars gatherings from different localities, cover with plates of glass, put in warm places and, in most cases, in fairly strong

light. If the green plants are sought, exposure to direct sunlight is advised. If Fungi are under cultivation, the strong sunlight should be avoided. The light of almost any ordinary room affords a sufficient variety of conditions for nearly all sorts of cultivations, though some of the Fungi may be raised to advantage in a damp cellar. If the cultivations are being made during the summer months, the temperature will take care of itself; in the winter, to insure success, care must be taken that it does not fall much below 70° F. at any time, day or night.

In making the collections, not only should the different known plants be placed in separate jars and the jars be filled with water from the native habitat, but gatherings of mud and débris from even unpromising localities should be utilized. Such unpromising collections often yield most surprising and interesting results. For instance, the finest forms of that most fascinating organism — Pandorina — which the writer has ever seen were developed in a jar in which a clump of violets were kept with just moisture sufficient to give vigorous growth to the violets.

When rare plants or conjugating forms are secured, some of them should be preserved in formalin or alcohol to use in case subsequent cultures and search of the ponds and streams fail to produce what is wanted.

A box with glass front and back and a plate of glass for a cover is very useful for the cultivation of Vaucheria, Liverworts, Mosses, Drosera, and many other like plants. It should stand in a window and should have three or four inches of good swamp mud in the bottom.

A large table, with a sink in its center provided with running water, is also convenient for the cultivation of many plants. Boxes of sawdust and earth arranged around this table may be utilized for the production of seedlings. Rich earth may be placed in the bottom of the sink, and water plants may be grown. A small jet of

water playing in the sink will keep the air moist or may be used to spray the plants arranged around the sides of the sink. The water jet should be connected with the pipes by means of a flexible rubber tube so that it may be moved about at will.

2. THE LABORATORY.

A room with northern exposure is to be preferred for the laboratory, as the light from the north gives more uniform conditions for the use of the microscope. It should be well lighted by large windows and should be supplied with running water. The students' working tables should have flat tops, with a raised rim at the back and sides to guard against dropping reagent bottles and other apparatus. A number of cabinets and dark closets are desirable for storing apparatus and collections of material for study.

While a fully equipped laboratory is much to be desired, still all the work described in this book may be advantageously done in an ordinary schoolroom and on common desks. The entire cost of fitting up a Botanical Laboratory with convenient appliances, including microscopes, microtome, and accessory apparatus, is less than the expenditure necessary for a Physical or Chemical Laboratory, and the Botanical Laboratory, once equipped, calls for very little expenditure from year to year.

3. THE MICROSCOPES.

Microscopes that are powerful enough for all the observations described in this course and that are good enough to place in the hands of beginners may be imported, duty free, for about $18.50. American-made microscopes of equal desirability cost somewhat more. In the selection of microscopes the quality of the objectives is of the greatest

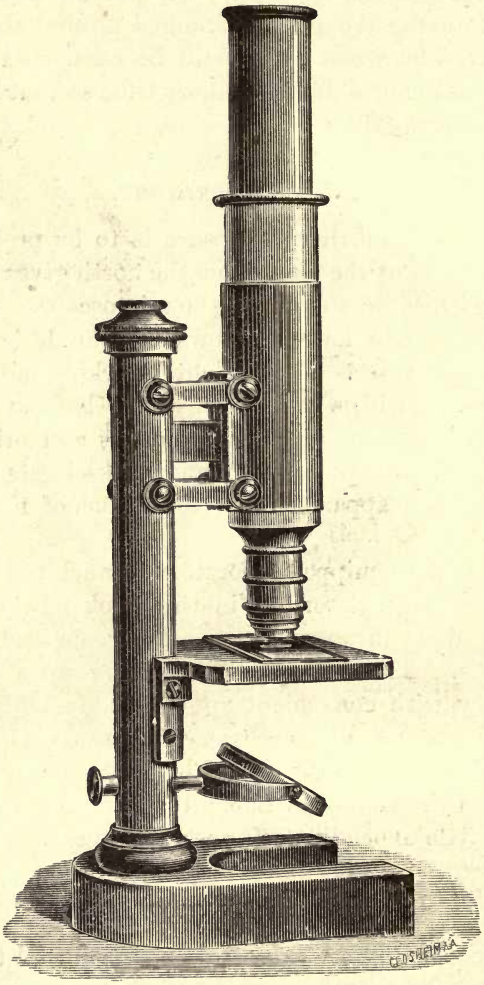

FIG. 189. — Leitz Stand V.

(Cut furnished by The L. E. Knott Apparatus Co., Boston.)

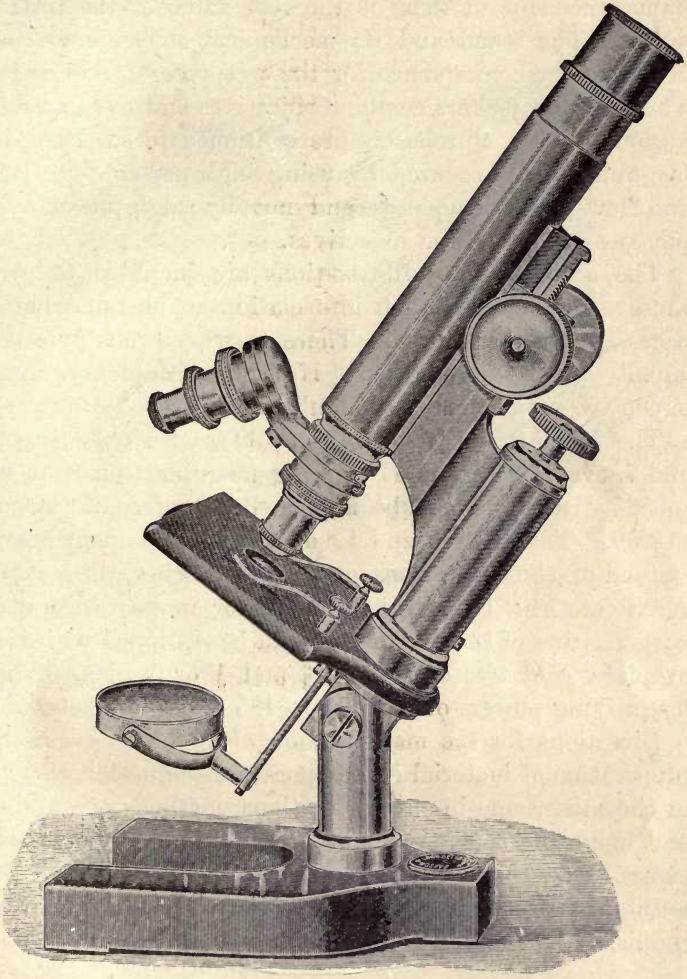

FIG. 190. — Bausch and Lomb Stand AAB.

(Cut furnished by the Bausch and Lomb Optical Company, Rochester, N. Y.)

importance, for in them is the real value of the instrument. The stand and its mechanical conveniences are of secondary consequence for the purposes of this work. The different makers combine objectives and eyepieces in various ways. Purchasers are cautioned to see that the magnification is secured by using high-power objectives and low-power eyepieces and not by high-power eyepieces and low-power objectives.

The accompanying illustrations are included to give those who may need such information an idea of what is necessary for this course. There are very probably other equally good microscopes. If funds are plenty, more expensive stands may be indulged in.

The Leitz Stand V (see Fig. 189), with objectives 3 and 7, eyepieces I and III, giving magnification from 60 to 525 diameters, may be imported, duty free, for about $18.50. The Bausch and Lomb Optical Company make a stand of about the same grade and another, their stand AAB (see Fig. 190), which is superior in its mechanical parts; either of these stands should be equipped with two eyepieces and two objectives, $\frac{2}{3}$ and $\frac{1}{6}$ or $\frac{1}{8}$ inch, giving magnifying powers of from 55 to 485 or 770 diameters.

Directions for the manipulation of the microscope, the preparation of material for temporary examination, the use of the microtome in cutting sections, methods of staining and mounting for permanent preservation, and the processes used in making photomicrographs, are given in the author's "Practical Methods in Microscopy," 2d edition, published by Messrs. D. C. Heath & Co., Boston.

4. ACCESSORY APPARATUS.

A microtome of some sort is a necessity. If one of the more expensive instruments cannot be afforded, a simple hand section cutter should certainly be obtained. The

list price of the one shown in Fig. 191 is $6.00. Such an instrument affords means of cutting sections in abundance when great delicacy is not of importance. To do more delicate work a more perfect instrument is required. If the laboratory is provided with one of the larger microtomes, some form of freezing attachment will reduce very much the labor of making sections in large quantities. Of these, that for the use of carbonic acid gas is most to be desired. If this cannot be afforded, Osterhout's attachment for the use of ice water should be obtained. It is listed at $2.50. The writer has found it a thoroughly practical and satisfactory accessory.

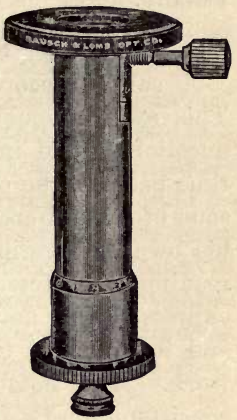

FIG. 191.—Simple Hand Section Cutter.

Of other apparatus, there should be a supply of glass slips and cover glasses, dissecting needles, scalpels or razors, watch glasses, Petri dishes of different sizes, flasks, and beakers, all of which are comparatively inexpensive.

The teacher should gradually accumulate microscope slides, and photomicrographs, to illustrate the more difficult points. These are especially to be commended in the case of observations that would consume the time of the class unwarrantably. Valuable additional instruction may also be given in lectures and informal talks, especially if apparatus for projecting microscopic sections and lantern slides is available. The L. E. Knott Apparatus Company, Boston, have undertaken, at the writer's request, to furnish a set of lantern slides to illustrate this course. They also furnish, at popular prices, new forms of projection apparatus, using as the source of light arc or incandescent electric lamps, acetylene gas, Welsbach burners, or kerosene lamps. The slides will include about

75 photomicrographs from the author's original negatives, and many reproductions of figures in standard works on Botany.

5. THE NOTEBOOK.

A careful record of the work done should be kept. This record should not consist merely of answers to the questions asked in the Practical Studies, but, so far as time permits, the pupil should be asked to make comparisons of the different plants studied, using the results of his own observations and material gathered by carefully reading the references given. He should be required to express plainly and accurately in clear, idiomatic English and in drawings the carefully thought-out results of his work. The notebook, when finished, should contain a consistent bird's-eye view of the plant kingdom. It should be an evidence of the pupil's growth in knowledge; but, even more important than this, it should be a means of training him to the correct use of English in the expression of the ideas he has acquired. In the writer's judgment, no subject in the school curriculum affords more or better material for the solution of the "English problem" in the schools than such a course of botanical study properly carried out.

6. REAGENTS.

a. **Formalin.** — Formalin, 1 part; water, 70 parts; enough chrome alum to give a deep green color. This is one of the best preservatives.

b. **Alcohol** of from 70 to 90 per cent strength may be used as a preservative.

c. **Iodine Solution.** — Make a saturated solution of potassium iodide in water and add as much iodine as will dissolve. This is the common test for starch. It turns the starch granules blue or blue-black.

d. **Schultze's Solution.** — Dissolve as much metallic zinc in hydrochloric acid as will dissolve; then add as much iodine as will dissolve; filter through glass wool. This is the test for cellulose; it turns normal cellulose blue or violet, fungous cellulose yellowish brown.

e. **Schultze's Macerating Mixture.** — This consists of nitric acid to which a few crystals of potassium chlorate are added when used. This solution is used to separate the fibers of woody tissues. The piece of plant should be placed in a test tube, covered with nitric acid, and a little potassium chlorate added. The tube should be heated to the boiling point, and then its contents should be poured into a large volume of water to stop the action and wash out the acid. The plant tissues can then usually be easily separated with dissecting needles.

f. **Caustic Potash.** — The usual strength should be 1 g. of the solid to 20 c.c. of water. This is used as a macerating fluid, and also to cause the cellulose constituents of plants to swell and become more plainly visible under the microscope.

g. **Millon's Reagent.** — Dissolve a small globule of mercury in nitric acid and add an excess of the acid. This solution is used to test for protein; it turns proteinaceous substances red.

h. **Osmic Acid.** — This expensive reagent may be purchased in tubes containing 1 g. each. The tube should be broken under the surface of the water in which its contents are to be dissolved, as the fumes from the acid are very disagreeable and poisonous. One gram to 500 c.c. of water is a good strength for ordinary use. The solution does not keep well. It is the test for oils and fats.

i. **Sulphuric Acid.** — The commercially pure acid should be used either in full strength or diluted to various degrees. This acid dissolves pure cellulose, but acts only slightly on the older modified forms of cellulose.

j. **Sachs' Solution.** — Potassium nitrate, 1 g.; sodium chloride, 0.5 g.; calcium sulphate, 0.5 g.; magnesium sulphate, 0.5 g.; calcium phosphate, 0.5 g.; distilled water, 1 l.; two or three drops of iron chloride. Heat. Only a part of the calcium phosphate will dissolve. The whole should be shaken each time a part of the stock solution is taken for use. This is the nutrient solution to be used in experiments on green plants.

k. **Pasteur's Solution.** — Water, 838 c.c.; sugar, 150 g.; ammonium tartrate, 10 g.; potassium phosphate, 2 g.; calcium phosphate, 0.2 g.; magnesium sulphate, 0.2 g. This is the solution to be used in the cultivation of the chlorophyl-less plants. For some purposes, the sugar may be omitted; in other cases, its amount is sometimes varied.

INDEX.

Achlya prolifera, 135.
Adder Tongues, 187.
Æcidiomycetes, 13, 121, 157.
Æcidiospores, 157.
Æthalium septicum, 50.
Agaricineæ, 161 *et seq.*
Agaricus campestris, 160.
Albumen, 17.
Albuminous, 17.
Algæ, 13, 70 *et seq.*
Alternation of generations, 9, 10, 58, 59, 185.
Amœba, 47, 48.
Andrœcium, 206.
Anemophilous flowers, 25.
Angiosperms, 13, 15, 27, 206, 218 *et seq.*
Annular vessels, 217, 229, 231.
Annulus, 162, 195.
Anomalous dicotyledons, 232.
Antheridium, 36, 91, 108, 112, 116, 169, 174, 180, 181, 184.
Antherozoids, 10, 36, 38, 71, 77, 91, 109, 113, 116, 169, 174, 177, 180, 181, 184.
Apical bud, 190, 191, 207, 234.
Apical cell, 190, 191.
Apical meristem, 234.
Apogeotropism, 18.
Apothecium, 141.
Archegoniates, 10.
Archegonium, 10, 36, 38, 106, 169, 174, 177, 181, 182, 184.
Areolæ, 171.
Ascent of nutrient fluids, 245.
Ascogonium, 156.
Ascomycetes, 13, 121, 136.
Ascospores, 136, 147, 149, 156.
Ascus, 136.
Autonomous movements, 250.
Auxospores, 58.

Bacteria, 13, 59, 63 *et seq.*
Basidia, 164.
Basidiomycetes, 13, 121, 160 *et seq.*
Basidiospores, 164.
Bast, 229, 230, 231.
Black molds, 125.
Blights, 138.
Blue-green slimes, 13, 59 *et seq.*
Boletus, 164.
Bordered pits, 215, 217.
Botrychium, 187.
Brake Fern, 187 *et seq.*
Brittleworts, 106.
Brown Algæ, 13, 71, 110.
Bryophytes, 9, 10, 13, 167 *et seq.*
Budding, 148.
Buds, 22.
Bunts, 122.
Button, 160.

Calyptra, 179.
Cambium, 213, 214, 230, 231.
Capillarity, 243.
Capitulum, 109.
Carbon dioxide, 22, 100, 237.
Carpel, 33.
Caulicle, 222.
Cedar apples, 158.
Cellular Cryptogams, 183.
Cellulose, fungous, 107.
Cellulose, test for, 75.
Chætophora, 87.
Characeæ, 104 *et seq.*
Chlamydospores, 127.
Chlorococcus, 81.
Chlorophyceæ, 13, 71 *et seq.*
Chlorophyl, 42, 44, 46, 54, 59, 100, 211, 226.
Chromatophores, 100.
Chroöcoccaceæ, 60.
Chroöcoccus, 60.
Chytridieæ, 13, 121.
Cilia, 44, 111.
Circumnutation, 250.

Cladophora, 88.
Clavarieæ, 161, 165.
Club Mosses, 13, 186, 202 *et seq.*
Cœloblastæ, 71 *et seq.*
Cœnobium, 78.
Coleochæteæ, 90, 92, 93.
Colloids, 242.
Columella, 129.
Commensalism, 139.
Conceptacles, 114.
Cones, 209.
Conifers, 206 *et seq.*
Confervoideæ, 71, 87.
Conjugatæ, 71, 93 *et seq.*
Contractile vacuoles, 49, 86.
Coral-shaped Toadstools, 161, 165.
Corn, 221.
Cotyledons, 15, 16.
Cross-fertilization, 25.
Crystalloids, 242.
Crystals, 228.
Cupules, 168, 169.
Cyanophyceæ, 13, 59 *et seq.*
Cycads, 206.
Cyclosis, 107.
Cystopus, 130, 133.

Deliquescent stems, 27, 207.
Descent of nutrient fluids, 245.
Desmidieæ, 94 *et seq.*
Desmids, 94, 95, 96.
Diastase, 243.
Diatomaceæ, 13, 54 *et seq.*
Diatomin, 54.
Diatoms, 13, 54 *et seq.*
Dicotyledons, 15 *et seq.*, 220, 225 *et seq.*
Dicotyledons, anomalous, 232.
Dicœcious plants, 23.
Dionæa, 254.
Drosera rotundifolia, 254.

Eagle Fern, 187 *et seq.*
Elaters, 175, 200, 202.
Embryo, 16, 205, 218.
Embryo sac, 205, 209, 219.
Endochrome, 83, 89.
Endosmosis, 75.
Endosperm, 17, 209, 219.
Entomophilous flowers, 25.
Epidermis, 21, 213, 226, 233.
Equisetinæ, 13, 186, 200 *et seq.*
Equisetum arvense, 200.
Equisetum sylvaticum, 200, 201.
Ergot, 147.
Euglena viridis, 45.
Eurotium, 155.
Exalbuminous seeds, 17.
Excurrent stems, 27, 207.

Ferns, 3, 13, 34 *et seq.*, 183 *et seq.*
Fertilization of flowers, 24, 206, 219, 221.
Fibrovascular bundles, 10, 35, 179, 183, 211, 220, 224, 233.
Filicinæ, 13, 186 *et seq.*
Fission plants, 13, 59, 63.
Flagellum, 46, 79, 85, 89.
Florideæ, 71, 118, 119.
Flowering plants, 1, 15 *et seq.*, 205 *et seq.*
Flowers of Tan, 50.
Flowers, parts of, 23.
Flowers, anemophilous, 25; complete, 23; dicœcious, 23; entomophilous, 25; female, 23; fertilization of, 24; gamopetalous, 24; gamosepalous, 24; hermaphrodite, 23; male, 23; monœcious, 23; perfect, 23; pistillate, 23; polypetalous, 24; polysepalous, 24; staminate, 23.
Fruit, 26.
Fruit dots, 35.
Fucaceæ, 111 *et seq.*
Fucus vesiculosus, 112 *et seq.*
Funaria hygrometrica, 181.
Fungi, 13, 120 *et seq.*

Gamete, 3, 36, 38.
Gametophyte, 3, 36, 38, 89, 167, 205.
Gamopetalous flowers, 24.
Gamosepalous flowers, 24.
Gasteromycetes, 161, 165.
Gemma, 10, 167, 170, 173.
Geotropism, 17, 129, 247.
Gill-bearing Toadstools, 161 *et seq.*
Glœocapsa, 60.
Glycogen, 129.
Gonidia, 10, 76, 89, 132, 142, 164.
Gonidiophores, 135.
Green Algæ, 13, 71 *et seq.*
Green Felts, 73.
Guard cells, 21.
Gymnosperms, 13, 31 *et seq.*, 206 *et seq.*
Gynœcium, 206.

Hæmatococcus, 84.
Hairy-cap Moss, 177 *et seq.*

Hanging-drop cultures, 129.
Haustoria, 130, 134.
Heat, 240.
Heliotropism, 18, 130, 247.
Hepaticæ, 13, 167.
Herbarium mold, 155.
Heterocysts, 60.
Heterogamous union, 71.
Hilum, 16.
Hormogonia, 61.
Horsetails, 13, 186, 200 *et seq.*
Hydneæ, 161, 165.
Hydrodictyon, 82.
Hydrotropism, 248.
Hymenium, 144, 164.
Hypha, 120, 127.
Hypocotyl, 15.

Indusium, 35, 196.
Innovation, 168.
Internode, 20.
Iodine solution, 74, 85, 100.
Isoëteæ, 204.
Isogamous union, 87.

Joint Firs, 206.

Kelp, 111.

Laminaria, 111.
Latex tubes, 230.
Leaf scars, 20.
Leaves, 18, 19.
Lichens, 138, 139 *et seq.*
Liverworts, 13, 167 *et seq.*
Lycopodinæ, 13, 186, 202 *et seq.*
Lycopodium clavatum, 203; complanatum, 203; dendroideum, 204.

Macrospores, 11, 205.
Manubrium, 109.
Marchantia polymorpha, 167 *et seq.*
Marattiaceæ, 187.
Marsiliaceæ, 186.
Medullary rays, 214, 215, 233.
Megazoöspores, 85, 86, 89.
Meristem, 210, 234.
Mesophyll, 195, 211.
Mesocarpeæ, 94, 103.
Micropyle, 16, 209.
Microspores, 11, 205.
Microzoöspores, 83, 85, 87, 89.
Mildews, 13, 121, 125, 130.
Millon's reagent, 241.
Mimosa pudica, 253.
Molds, 13, 42, 121, 125.
Monocotyledons, 27 *et seq.*, 220 *et seq.*
Monœcious plants, 23.
Mosses, 13, 38 *et seq.*, 167, 176 *et seq.*
Moss plants, 9, 10, 13, 167 *et seq.*
Moonworts, 187.
Movements, autonomous, 250; due to irritation, 253; twining, 249.
Mucorineæ, 125.
Mucor mucedo, 126.
Mucor stolonifer, 127.
Musci, 13, 167 *et seq.*
Mushrooms, 160 *et seq.*
Mycelium, 120, 125.
Mycetozoa, 50.
Myxomycetes, 13, 50 *et seq.*

Nitella, 104.
Nodes, 20.
Nostocaceæ, 60, 61, 62.
Nucellus, 207, 209, 210.
Nucleus, 102, 208, 235.
Nucleolus, 208, 235.

Œdogonieæ, 90.
Œdogonium, 90 *et seq.*
Oil, test for, 75, 155.
Oögamous union, 71.
Oögonium, 76, 91, 113.
Oösphere, 10, 36, 38, 71, 116.
Oöspore, 9, 10, 37, 38, 71, 91.
Operculum, 182.
Ophioglosseæ, 187.
Oscillatorieæ, 60, 61, 62.
Osmic acid, 75, 129, 155.
Osmosis, 18, 22, 44, 55, 128, 236, 242.
Ostiole, 114.
Ovary, 24, 218.
Ovule, 24, 207, 219.
Oxalate of lime, 228.
Oxalis, 253.
Oxygen, 22, 85, 101.

Pandorina, 78.
Paramœcium, 47.
Paraphyses, 116, 144, 147, 164, 180.
Parasite, 120.
Parenchyma, 211, 213, 224, 227, 233.
Parthenogenesis, 103, 106, 121, 135, 136.
Pasteur's solution, 129, 148, 152.
Pediastrum, 82.

Pellicle, 68.
Penicillium crustaceum, 153; glaucum, 152 *et seq.*
Peristome, 182.
Perithecium, 147.
Peronosporeæ, 130.
Phæophyceæ, 13, 110.
Phæosporeæ, 110, 111.
Phagocytes, 51.
Phloëm, 212, 227, 231.
Phycocyanin, 59.
Phycoerythrin, 118.
Phycomycetes, 13, 121, 125.
Phycophæin, 110.
Phyllotaxy, 20.
Picric acid, 151.
Pileus, 162.
Pines, 206 *et seq.*
Pinna, 35.
Pinnules, 35.
Pistil, 218.
Pith, 26.
Pitted ducts, 231.
Plants, chlorophyl-bearing, 44; chlorophyl-less, 44; holophytic, 44; saprophytic, 44.
Plasmodium, 52.
Plasmolysis, 75, 150.
Plumule, 16, 222.
Pollen, 11, 23, 24, 25, 205, 208, 218, 219.
Pollen sac, 208.
Pollinodium, 156.
Polymorphism, 121.
Polypetalous flowers, 24.
Polyporieæ, 161, 164 *et seq.*
Polysepalous flowers, 24.
Polytrichum commune, 177 *et seq.*
Pond scum, 40 *et seq.*
Primordial utricle, 75, 101.
Prolification, 177.
Promycelium, 122.
Protein, test for, 241.
Prothallium, 10, 11, 36, 37, 184, 198, 205.
Protista, 45, 50, 63, 64.
Protococcaceæ, 71, 81 *et seq.*
Protococcus, 42 *et seq.*, 81, 84 *et seq.*
Protonema, 10, 36, 40, 169, 177, 197, 198, 199.
Protoplasm, 44, 45, 49, 59.
Pteridophytes, 3, 13, 183 *et seq.*
Pteris aquilina, 187 *et seq.*
Ptomaines, 65.
Puccinia graminis, 157; maidis, 159; rubigo-vera, 158.
Puff Balls, 161, 165.
Pulvinus, 251.
Pyrenoids, 100.
Pyrenomycetes, 147.

Radicle, 16, 222, 235.
Raphidium, 81.
Red Algæ, 13, 71, 118, 119.
Resin ducts, 213, 215.
Resting spores, 52, 86, 91.
Rhachis, 35.
Rhizines, 141.
Rhizoids, 10, 38, 167, 172, 175, 179.
Rhizomes, 34, 188.
Rhodophyceæ, 13, 71, 118, 119.
Rivularieæ, 60, 61.
Rockweeds, 111 *et seq.*
Root cap, 223; hairs, 17, 237; pressure, 18.
Roots, 27, 235.
Rotation of protoplasm, 107.
Rusts, 13, 121, 125, 157 *et seq.*

Saccharomyces, 138, 148 *et seq.*
Sac Fungi, 13, 121, 137.
Sach's solution, 101, 238, 239, 245.
Salvinaceæ, 186.
Saprolegnieæ, 135.
Saprophyte, 120.
Scalariform vessels, 229, 231, 233.
Scenedesmus, 81.
Schizomycetes, 13, 59, 63.
Schizophytes, 59.
Schultze's solution, 75, 85, 102, 114, 116, 129, 134, 143, 150, 179; macerating mixture, 180, 192, 194, 225, 229.
Sclerenchyma, 35.
Scytonemeæ, 60.
Sea Lettuce, 88.
Seed coat, 15, 16.
Seed plants, 3, 13, 205 *et seq*
Seeds, 26, 33, 206, 209, 219, 221.
Selaginelleæ, 204.
Self-fertilization, 25.
Sensitive plants, 253.
Seta, 38, 179, 182.
Sieve tubes, 216, 229, 231.
Siphoneæ, 71, 72 *et seq.*
Sleep, 250.
Slime Fungi, 13, 50 *et seq.*
Slipper animalcules, 47.

Smut Fungi, 13, 121, 122.
Soredia, 145.
Sori, 35.
Spermaphytes, 9, 13, 205 *et seq.*
Spermatia, 145.
Spermatozoids, 10, 71.
Sphæropleæ, 90.
Spiral vessels, 217, 229, 231.
Spirogyra, 41, 98 *et seq.*
Sporangia, 36, 38, 128, 182, 195, 197.
Spore, 9, 36, 38, 198, 199, 202; resting, 52, 86, 91.
Sporophyte, 9, 36, 89.
Starch, test for, 74.
Stems, deliquescent, 27; excurrent, 27.
Sticta pulmonacea, 140.
Stigma, 24.
Stipe, 35.
Stomata, 21, 22, 114, 130, 171, 172, 194, 212, 224, 226; water, 22.
Stonewort, 106.
Style, 24.
Sugar, 241.
Sundew, 254.
Sunlight, 245.
Symbiosis, 139.
Symmetrical flowers, 30.

Taproot, 17.
Teleutospores, 157.
Testa, 16.
Tetraspora, 81.
Thallophytes, 3, 13, 41.
Thallus, 3, 41, 121, 139.
Tilletia caries, 122, 123.
Toadstools, 13, 121, 160 *et seq.*
Tooth-bearing Toadstools, 161, 165.
Toxins, 65.
Tracheïdes, 217.
Trama, 164.
Transpiration, 21, 244.
Trichogynes, 145.
Truffles, 138.
Tube-bearing Toadstools, 161, 164 *et seq.*
Twining movements, 249.

Ulva, 88, 89.
Uredineæ, 157 *et seq.*
Uredospores, 157.
Usnea barbata, 140.
Ustilagineæ, 13, 121, 122.
Ustilago maidis, 123, 124.

Vacuoles, contractile, 49, 86.
Vascular Cryptogams, 183.
Vaucheria, 73 *et seq.*
Vaucheriaceæ, 73.
Velum, 162.
Venation, 19.
Venus' Flytrap, 254.
Vernation, 19.
Volva, 162.
Volvocineæ, 71, 77 *et seq.*
Volvox, 79.

Water Flannel, 88.
Water mold, 125, 134.
Water net, 82, 83.
Wheat Bunt, 122.
Work, 246.

Xylem, 211, 215, 227, 231.

Yeast, 138, 148 *et seq.*

Zoöglœa, 68.
Zoögonidia, 122.
Zoöspore, 43, 58, 70, 76, 85, 87, 89, 113, 122.
Zygnemeæ, 94, 97.
Zygospore, 9, 41, 58, 71, 89, 98, 102, 125, 127.

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